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SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

II. SOIL DEPTH, MOISTURE HOLDING CAPACITY, AND pH[1]

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This paper is the second in a series reporting the findings of an investigation started in 1937 into the effects of certain factors on apple tree performance in the Okanagan Valley in British Columbia. The first paper (25) dealt with tree size, tree vigour, biennial bearing, and distance apart of planting. This present paper deals with soil depth, moisture holding capacity, pH, and lime content.

REVIEW OF LITERATURE

A great deal of investigational work has been reported on the effects of the physical and chemical nature of the soil on fruit tree performance. It will be considered sufficient here to review briefly some of the more important findings dealing with the effects of the physical nature and pH of the soil on apple tree growth and yield.

Physical Nature of Soil

Among the most important factors associated with the physical nature of the soil are texture, depth, moisture holding capacity, hard-pan, and natural drainage. Texture and depth are very closely related to the moisture holding capacity, as reported previously by the author (26). In 1915, Wilder (28) recommended for the Baldwin variety a medium to semi-light soil, and for the McIntosh a soil somewhat heavier[3] than this. In 1930, Heinicke and Batjer (7) in New York found a clay subsoil to be deleterious to the growth of apple trees. In 1932, Collison, Collison and Harlan (4) reported that the sand content of a New York soil was positively correlated with the yield of Baldwin, but not with the yield of Greening. The same year, Veatch and Partridge (23) and Partridge and Veatch (19) in Michigan found too light or shallow a soil to be undesirable, as also was an acid hardpan or clayey subsoil; and Oskamp and Batjer (17) in New York reported that a deep loam soil was best suited to the growth of Baldwin trees. A clay subsoil or hardpan and a high water table were not conducive to good tree performance. At various times since then, Oskamp

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[3] In this paper, a "light" soil is used to mean a sandy soil, and a "heavy" soil is used to mean a fine silt or clay soil.

and his co-workers (1, 14, 15, 16) have reported similar findings with New York soils. In 1933, Oskamp (14) obtained a positive correlation between depth to the ground water table and the yield of Baldwin trees. In 1934, Veatch and Partridge (24) in Michigan recommended light to heavy loams, underlaid at 10 to 15 inches depth by a heavy loam, penetrable for tree roots to 10 feet or more. In 1935, Sweet (22) recommended a deep soil: one that is not too light, with too low a moisture holding capacity; and not too heavy, with too little permeability to water and air. Good soil structure and drainage were stressed. Similar recommendations have been made since by Magness, Degman and Furr (10), Partridge and Veatch (20), Morgan, Gourley and Albeiter (13), Browning and Sudds (2) and Magness (9). It appears to have been generally agreed (14, 16, 20) that for best results a depth of at least 5 feet of soil free from hardpan or excess water is required. Oskamp (14) found a good positive correlation between yield and the depth of the water table. Magness (9) stressed the importance of the moisture holding capacity of orchard soils. Gardner, Bradford and Hooker (6) felt that the varietal preferences reported by Wilder and others are open to question. It should be noted that all of these references dealt primarily with non-irrigated areas.

Soil pH

Little appears to have been reported on the effects of soil pH on apple tree performance. In 1932, Oskamp and Batjer (18) in New York reported that within a pH range of 5.4 to 7.8 there was a good negative correlation between pH and yield with Baldwin; but that the correlation was not significant with Greening. In 1934, Veatch and Partridge (24) in Michigan were unable to specify any definite optimum within a pH range of 4.5 to 7.5. In 1937, Morgan (12) in Connecticut suggested a pH range of 5.4 to 6.8 as being desirable for apples. In 1941, Spurway (21) in Michigan specified a pH range of 5.0 to 6.5 as being the optimum for apples. Morgan, Gourley and Albeiter (13) considered the apple to be adapted to a wide pH range, but cautioned against the use of soils sufficiently alkaline to cause chlorosis. Loughridge (8) listed the apple as being highly susceptible to injury from sodium carbonate, which produces black alkali in the soil.

The relation between the lime content and the pH of the soil has received considerable attention. Buehrer and Williams (3) found that when no black alkali was present, soil with 20% lime had a pH of around 7.5; with 70% lime, a pH of around 8.0. McGeorge (11) found calcareous soils containing no alkali to range around pH 8.0.

PROCEDURE

Tree Records

In the first paper of this series (25), the general experimental set-up and the procedures used in obtaining the tree records were described. Groups of 5 mature or nearly-mature McIntosh trees were selected in grower-owned orchards from Penticton to Oyama. Annual records were taken for 6 years (1937 to 1942) on trunk circumference, terminal length, total yield, and "profitable" yield. This last consisted of fruits falling within the diameter range of $2\frac{1}{4}$ to $3\frac{1}{8}$ inches, and showing 20% or more of solid red colour. From the trunk circumference was calculated the "trunk-ground ratio," a measure of tree size per unit area of ground occupied; and

from the yields was calculated the "biennial bearing index," a measure of the degree of biennial bearing. These data were all averaged for 4-year or 5-year periods, depending on their biennial bearing status.

For the purpose of comparison with the soils data, the tree data have all been averaged for each plot. The results are presented in Table 3 in the Appendix.

Soil Sampling

Soil samples were obtained from all plots during the months of April and May, 1940. In each plot, composite samples were taken around one tree only. The procedure used was as follows:

> (1) Make borings with a 1½-inch auger at each tree, and from the data thus obtained select the tree around which the soil appears best to represent the plot. (2) At distances of 4, 7 and 10 feet from the trunk, lay out a pattern of ten locations around this tree. (3) At each location, take a sample with the auger at a depth of 0 to 8 inches, and composite these samples. Mix thoroughly, pass through a 3-mm. screen, allow both soil and screenings to air dry, and weigh them to obtain the percentage of gravel larger than 3 mm. Discard the gravel. (4) In similar manner, make a composite from ten samples at the 8- to 24-inch level, and from five samples at the 24- to 60-inch level. If a mixture of clear sand and gravel is encountered above 60 inches, sample the top of this mixture only.

The three depths of sampling were selected after considerable study of root growth. The 0- to 8-inch depth was found to represent (usually) the area of greatest concentration of cover crop roots, combined with a low concentration of apple roots; the 8- to 24-inch depth represented the greatest concentration of apple roots; and the 24- to 60-inch depth represented a lesser concentration again of apple roots. In some soils, the roots descended much deeper than this, but they were usually sparsely scattered at the lower depths. The data on root growth will be reported in a subsequent paper.

Moisture Holding Capacity

The moisture holding capacity, expressed in inches of water per foot of soil (M.C.F.), was determined by the settling volume procedure outlined in a previous paper by Wilcox and Spilsbury (26). The following equation was used to transfer settling volume to moisture holding capacity:

Moisture holding capacity (M.C.F.) = $0.0760 \times$ settling volume $- 0.321$.

Each figure thus obtained was multiplied by the depth in feet, to obtain the amount of water held at each of the three depths. These were then added together, to obtain the amount held in the whole profile to the depth sampled. The purpose of this procedure has been discussed in a previous paper by Wilcox and Spilsbury (27). In making the calculations, corrections were made for the percentage of gravel over 3 mm., on the assumption that its moisture holding capacity was zero. Thus if the screened soil had a moisture holding capacity of 4.0 inches, but the gravel content of the unscreened soil was 25%, then the correct (adjusted) moisture holding capacity was assumed to be 75% of 4.0, or 3.0 inches. It was also assumed that the underlying mixture of coarse sand and gravel, found in many plots, had a moisture holding capacity of zero.

Lime Content of Soil

The approximate amount of carbonates present in the soil was determined by a quick test developed by the author. To establish a standard for this test, increasing amounts of C.P. calcium carbonate were mixed thoroughly in samples of a number of soils that originally showed no effervescence with hydrochloric acid. These mixtures (0 to 7% calcium carbonate) were treated by the same procedure as the unknowns, and from the data obtained a curve was established relating the lime content to the froth readings. The readings obtained from the unknowns were then transferred into carbonate readings, expressed in terms of lime content. The procedure used in obtaining the readings was as follows:

> Pour about 5 ml. of water into a tall 100 ml. graduated cylinder. Add 10.0 gm. of air-dried soil. Insert a long, strong stirring rod. Make up to 20.0 ml. with water, washing down the soil adhering to the side of the cylinder with it. Add in one motion 10.0 ml. of 1 normal hydrochloric acid, stir vigorously, and note the maximum height to which the froth rises. Determine carbonate content from chart.

Readings were made in duplicate, or in triplicate if the first two were not close enough together. The results shown in Column 7 of Table 4 are the averages, adjusted for gravel content.

Soil pH

The pH was determined with a glass electrode. Boiled distilled water was added to the soil until a "pasty" condition was obtained, as suggested by Doughty (5). The difference between the pH at this moisture content and that at the moisture holding capacity was found to be scarcely measurable in most cases. Readings were made in duplicate, or in triplicate if the first two were more than 0.1 pH apart. The results shown in Column 6 of Table 4 are the averages. The pH values of the different soil levels were averaged to obtain the "average" pH for each profile.

Statistical Procedures

The data obtained were examined statistically by means of correlations, regression lines, and scatter diagrams, as outlined in the first paper (25) of this series. The soils data were obtained from 74 plots, but the tree data were considered reliable from only 66 of these plots. These figures are mentioned in order to assist in interpreting the significance of the correlations reported below.

RESULTS

The more pertinent of the data on which this report is based are tabulated in the Appendix. In Table 3 are shown the number of trees per plot, the trunk-ground ratio (a measure of tree size per unit area of ground), and the plot averages of terminal length, biennial bearing index, total yield per acre, and profitable yield per acre. These were all calculated from the "Summary" data described and presented in Paper I (25) of this series. In Table 4 are shown the soil depth, gravel content, moisture holding capacity per soil layer and per profile, moisture holding capacity per foot of soil, pH, and lime content.

Soil Depth

Only 22 plots out of 75 had five feet or more of soil that could be classed as suitable for normal root growth. As will be seen from Column 2 of Table 4, a high percentage of the plots had only about two feet of soil. Where the soil was less than 60 inches in depth, it was in all cases underlaid by a mixture of clear gravel and coarse sand, in various proportions. Where the soil was deeper than 60 inches, no attempt was made to determine its actual depth. There was no evidence of poor drainage in any of the plots. Such cases do occur in the Okanagan Valley, but care was taken to avoid them in the original selection of plots.

An examination of the data revealed that neither soil depth nor soil texture by itself was as important in influencing tree performance as were the two of them taken together. A convenient method of combining them was found to be in the form of the moisture holding capacity, expressed in inches of water (26); and this has therefore been the method used as a basis for making correlations.

Moisture Holding Capacity

The moisture holding capacity was expressed first as inches of water per foot of soil; and these figures were then adjusted for the gravel content, on the assumption that particles over 3 mm. in size had a moisture holding capacity of zero. The moisture holding capacity was reported previously (26) to show a high positive correlation with the colloid content, and a high negative correlation with the sand content. It was used in this investigation, therefore, as a convenient index of average soil texture.

TABLE 1.—RANGE OF EACH SOIL MEASUREMENT

Soil measurement	Soil depth	Minimum	Maximum	Mean
	inches			
Depth, in inches		17	60*	38.3
Gravel content (over 3 mm.) in per cent	0– 8	0	62.5	7.1
	8–24	0	64.0	20.8
	24–60	0	43.0	4.0
Moisture holding capacity, in inches of water per foot of soil†	0– 8	1.23	4.32	3.20
	8–24	0.94	4.62	2.84
	24–60	1.34	4.67	3.39
Moisture holding capacity, in inches of water per profile‡	0–60	2.86	23.05	9.19
Lime content, in per cent†	0– 8	0	1.4	0.03
	8–24	0	3.6	0.39
	24–60	0	6.2	2.31
pH	0– 8	5.67	7.64	6.54§
	8–24	5.98	8.19	6.97§
	24–60	6.65	8.34	7.52§
	0–60	5.91§	8.03§	6.91§

* The soil was not sampled below a depth of 60 inches.

† The moisture holding capacity has been adjusted for gravel content, on the assumption that particles over 3 mm. in diameter have a moisture holding capacity of zero. The mixture of coarse sand and gravel underlying the soil at varying depths was ignored. The lime content has also been adjusted for per cent gravel.

‡ Measured to the actual soil depth, the maximum of which was 60 inches.

§ Unweighted averages.

As will be seen from Table 1, there were wide variations both in the gravel content and in the moisture holding capacity. For the most part, the shallow soils had high gravel contents. Most of them also had low moisture holding capacities, even without adjusting for the gravel. On the other hand, the deeper soils contained very little if any gravel and had high moisture holding capacities. About one-half of the plot soils could be classed as shallow and sandy, about one-quarter as deep and heavy, and about one-quarter as intermediate in depth and texture.

Some correlations of the moisture holding capacity with the pH and with the tree data are presented in Table 2. The pH correlations are discussed below under "pH." The profile total of the moisture holding capacity (representing a combination of soil depth and texture) showed significant (odds 19 : 1 or better) or highly significant (odds 99 : 1 or better) positive correlations with terminal length, total yield, and profitable yield, and a significant negative correlation with biennial bearing index. In other words, the trees on the heavier and deeper soils tended to be more vigorous, to bear more regularly, and to have higher yields of both total and profitable fruit. Adjusting the total yield for differences in terminal length and biennial bearing index lowered the correlation somewhat. It appears that the higher yields found in the better soils could be attributed in part to better vigour and more regular bearing, and in part to other factors. Some of these other factors will be discussed in subsequent papers in this series.

TABLE 2.—SOME CORRELATIONS BETWEEN SOIL PROPERTIES AND TREE PERFORMANCE

Two sets of data correlated		Coefficient of correlation
M.C.F., *0– 8 inches	pH, 0– 8 inches	+ .084 (NS)§
M.C.F., 8–24 inches	pH, 8–24 inches	+ .554 (HS)
M.C.F., 24–60 inches	pH, 24–60 inches	+ .672 (HS)
Moisture capacity, profile total	pH, profile average	+ .586 (HS)
Moisture capacity, profile total	Trunk-ground ratio	+ .013 (NS)
Moisture capacity, profile total	Terminal length	+ .262 (S)
Moisture capacity, profile total	Biennial bearing index	− .267 (S)
Moisture capacity, profile total	Total yield	+ .410 (HS)
Moisture capacity, profile total	Total yield, 3 adjustments†	+ .272 (S)
Moisture capacity, profile total	Profitable yield	+ .393 (HS)
pH, profile average	Trunk-ground ratio	+ .020 (NS)
pH, profile average	Terminal length	+ .060 (NS)
pH, profile average	Biennial bearing index	− .038 (NS)
pH, profile average	Total yield	+ .267 (S)
pH, profile average	Profitable yield	+ .259 (S)
pH, 0–8 inches	Total yield	+ .151 (NS)
pH, profile average	Total yield, with M.C.F. effects eliminated‡	+ .036 (NS)
pH, profile average	Profitable yield, with M.C.F. effects eliminated‡	+ .039 (NS)

* M.C.F. Moisture holding capacity per foot of soil. It has been adjusted for the per cent gravel.

† Yields adjusted for all three of trunk-ground ratio, terminal length and biennial bearing index. All other yields noted in this table have been adjusted for trunk-ground ratio only.

‡ Partial correlations, with the M.C.F. held constant.

§ NS—Non-significant, with odds lower than 19 : 1.
S—Significant, with odds between 19 : 1 and 99 : 1.
HS—Highly significant, with odds higher than 99 : 1.

The scatter diagram of total yield plotted against total moisture holding capacity per profile is shown in Figure 1. It will be seen that although the general trend was a positive one, there were some fairly low yields on heavy, deep soils (i.e. those with high moisture holding capacities), and some fairly high yields on light, shallow soils. If the two plots with exceptionally high yields are ignored, there appears to have been a fairly steady increase in the maximum yield attained at each moisture holding capacity as this factor has increased. The differences in maximum (or "possible") yield that could be attributed to soil depth and texture alone, however, were not more than about 200 loose boxes per acre. The scatter diagram of profitable yield plotted against moisture holding capacity is very similar to that in Figure 1.

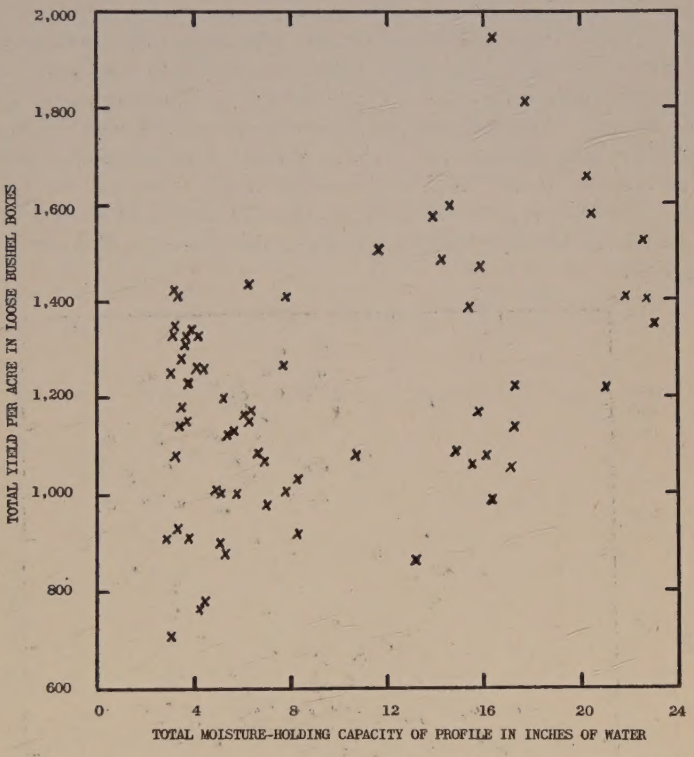

FIGURE 1. Scatter diagram of total moisture holding capacity of soil to 60 inches plotted against total tree yield. ($r = +.410$.)

Lime Content of Soil

Lime was present in the surface 8 inches of soil in only a very small percentage of the plots. It was suspected that wherever the lime appeared at or close to the surface, the original surface soil had been lost by erosion, or had been removed in levelling the soil prior to planting.

The presence of lime in the soil below a depth of 8 inches depended primarily on the texture of the soil. In sandy soil, no lime at all was recorded in the 8- to 24-inch layer, and almost none in the 24- to 60-inch layer. In the heavier soils, however, lime was usually present in moderate

amount in the 8- to 24-inch layer and in still higher amount in the 24- to 60-inch layer. Thus the heavier and deeper the soil and the higher the total moisture holding capacity, the higher also was the average lime content of the profile. Owing to the fact that so many of the profiles showed no free lime, no attempt was made to calculate any coefficients of correlation involving lime content.

Soil pH

The pH was affected by soil depth, soil texture, lime content, and fertilizers applied. The effects of the fertilizers will be reported in a subsequent paper.

Since the lime content of the soil was so closely related to soil depth and soil texture (as just noted), it was found difficult to separate entirely the effects of these three factors from one another. The presence of lime raised the pH to above 7.3 in every case, and usually to around 8.0. The pH tended to increase both with an increase in the lime content and with an increase in depth. The highest pH recorded was 8.34 (see Table 1), and the lowest with lime present was 7.35. With no measurable lime present, the pH was usually below 7.0, though occasionally it was above this figure. In one case (Plot W10, 24 to 60 inches), the pH was 8.24 with no evidence of any free lime, indicating the possibility of the presence of a small amount of black alkali.

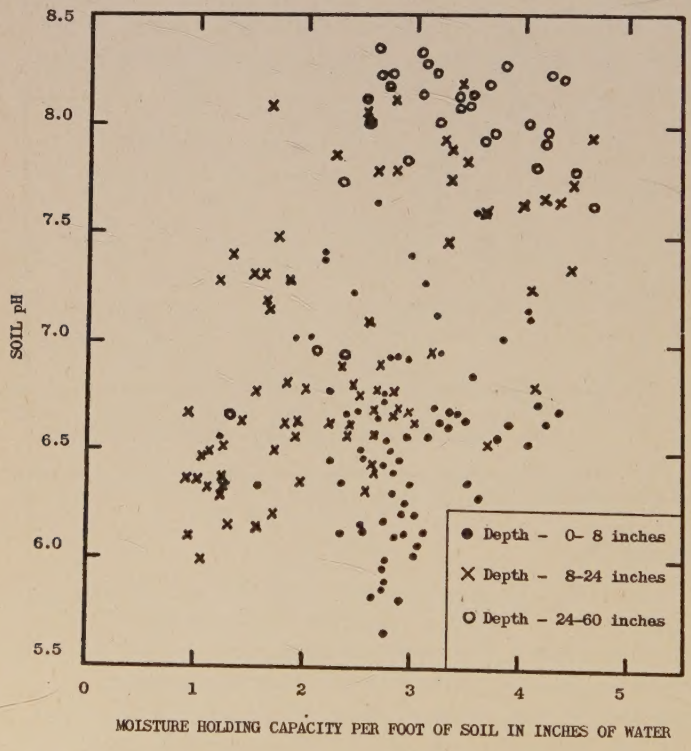

FIGURE 2. Scatter diagram of moisture holding capacity per foot of soil plotted against soil pH. Different marks are used for the three different soil depths. (At 0–8 inches $r = +.084$, at 8–24 inches $r = +.551$, and at 24–60 inches $r = +.672$.)

The pH varied with changes in the moisture holding capacity, and hence with changes in soil texture. Highly significant positive correlations were obtained between pH and moisture holding capacity per foot of soil in the 8- to 24-inch layer and in the 24- to 60-inch layer, but not in the 0- to 8-inch layer (Table 2). These relationships are illustrated in Figure 2. To some extent, the effect of soil texture is due to the presence of higher percentages of lime in the heavier soils. In the surface soils, however, the factor that has affected the pH the most appears to have been the cultural practices, more especially fertilizing and cover cropping.

The pH also varied with soil depth. In the heavy, deep soils there was almost invariably an increase in pH with increase in depth; but in a few of the light, shallow soils the pH was slightly lower in the 8- to 24-inch layer than in the 0- to 8-inch layer. The differences between the three layers studied are illustrated in Figure 2. When soil texture and depth were combined in the form of total moisture holding capacity per profile, this showed a highly significant positive correlation with the average pH of the profile (Table 2 and Figure 3). In other words, the heavier, deeper soils tended to have higher pH values than did the lighter, shallower soils.

The correlations between the average pH of the profile and tree performance are shown in Table 2. There was no evidence of any relationship between pH on the one hand and trunk-ground ratio, terminal length, or biennial bearing index on the other hand. There were significant positive correlations, however, between pH and yield (both total and profitable).

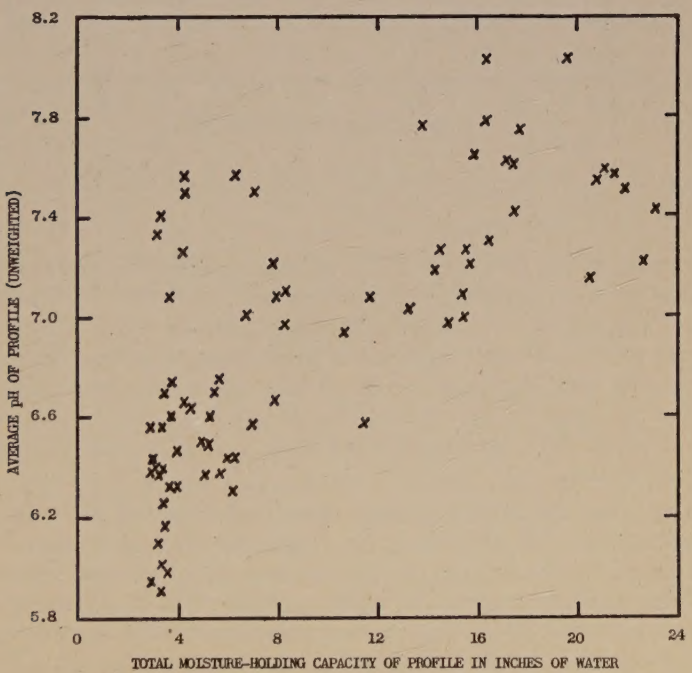

FIGURE 3. Scatter diagram of total moisture holding capacity of soil to 60 inches plotted against average pH of profile. ($r = +.586$.)

In other words, there was a distinct tendency for the higher yields to occur along with the higher average pH values. This is illustrated in Figure 4, showing total yield per acre plotted against average pH of profile. When

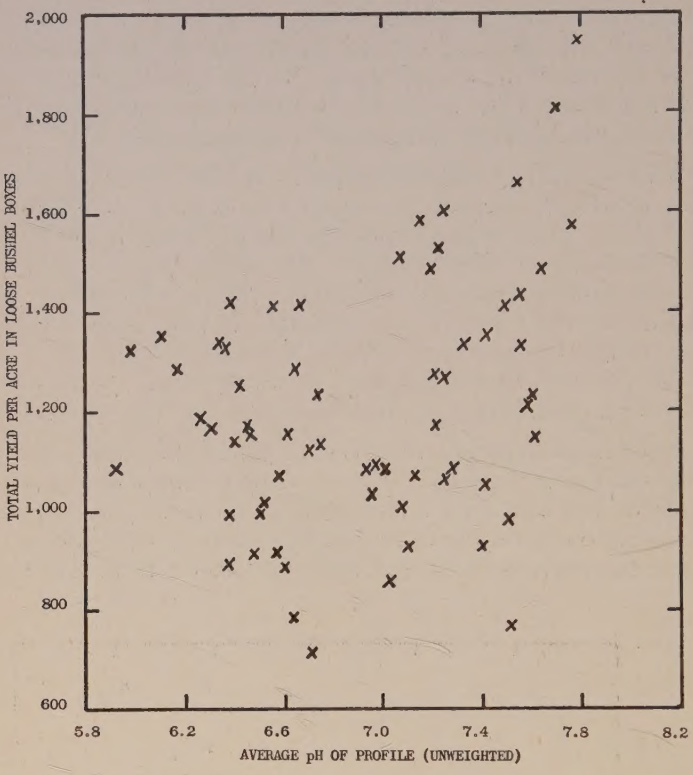

FIGURE 4. Scatter diagram of average pH of profile plotted against total tree yield. ($r = +.267$.)

the yield was correlated with the pH of the surface 8 inches only, the coefficient was positive and much lower in value. However, when the effects of moisture holding capacity were eliminated from the correlations between average pH and yield, the coefficients were reduced almost to zero, both with total yield and profitable yield. There is thus no proof that the pH of itself had any effect one way or the other on tree yield; in other words, the trees seem to have performed equally well at all points within the pH range of 6.0 to 8.0.

It should be noted that in the original selection of plots an attempt was made to avoid all areas showing black alkali; and as far as known, sufficient alkali was not encountered in any plot to cause injury to the plants. The positive correlation found between pH and yield appears to be due to some one or more factors (other than pH) that were closely associated with soil texture and depth.

DISCUSSION

It is of interest to compare the results obtained in this investigation with those reported by other workers. In New York (1, 4, 7, 17, 22), Michigan (20, 23), Virginia (2) and various other areas, heavy or slatey subsoils have been found to be deleterious to tree growth and production. The main reason for this has been the presence of poor drainage and a high water table, a combination frequently reported in the Eastern States and in Eastern Canada. Another reason has been the occasional presence of a true hardpan, which has been impervious not only to water but to tree roots as well. In the investigation reported herein, the deeper and heavier the subsoil (to a depth of 60 inches), the better on the average was the performance of the trees. However, there was in this case no high water table and no definite hardpan. There was no evidence of insufficient drainage in the plots studied. In some low-lying parts of the Okanagan Valley, seepage water is in evidence; but these areas were not encountered in this investigation. In only one case was there any evidence of root growth having been inhibited by a tight soil. As will be noted in a subsequent paper, the roots of apple trees were found to grow downward freely to a depth of at least 8 feet. One reason for this was that in the deeper soils the heaviest horizons (of laminated clay) were comparatively thin, and alternated with lighter layers rich in lime in a comparatively loose form. It is apparent from these findings that the presence of clay in the subsoil does not necessarily induce conditions unfavourable for normal tree growth.

Another relationship that does not conform to the findings of some other investigators is that found between soil pH and tree performance. In New York (18), a pH range of 5.4 to 7.8 was found to correlate negatively with yield of Baldwins. The optimum pH range specified for apples is 5.0 to 6.5 in Michigan (21) and 5.4 to 6.8 in Connecticut (12). In this present investigation, a pH range (profile average) of 5.91 to 8.03 was found to correlate *positively* with tree vigour and tree yield. By partial correlations, it was found that this correlation was caused not by any direct effect of soil pH on tree performance, but rather by a close relationship between soil pH on the one hand and soil depth and texture on the other hand. In other words, there was no evidence of either a beneficial effect or a deleterious effect of increasing pH within the range studied. This conforms to the findings of Veatch and Partridge (24) in Michigan.

It appears from this investigation that within a pH range of 6.0 to 8.0, any apparent effects of pH on tree performance cannot safely be attributed to pH alone; they are more likely to be due to other factors, with which the pH happens to be associated. In this case, the lowest pH values were found in the poorest soils, those that have been subject to the greatest leaching; and the highest pH values were found in the heaviest and deepest soils, which contain the greatest reserves of soil moisture and plant nutrients. In some other parts of the world, a high pH has no doubt been associated with certain undesirable conditions. In New York (18), for example, it appears in some case to have been associated with an impermeable subsoil.

SUMMARY

Growth and yield records were obtained from 74 plots (5 trees per plot) of McIntosh trees scattered through the Okanagan Valley from Penticton to Oyama. Soil samples were obtained in each plot at depths of 0-8 inches, 8-24 inches and 24-60 inches. Sampling was discontinued at the gravel if it was encountered at a lesser depth than 60 inches. Gravel content, moisture holding capacity (expressed both in per cent and in inches of water), lime content and pH were determined on each soil sample. The total moisture holding capacity per profile was used as a combination measurement of soil texture $\times$ depth.

The depth of soil ranged from 17 inches to at least 60 inches, the gravel content from 0 to 43%, the moisture holding capacity from 1.34 to 4.67 inches per foot of soil and from 2.86 to 23.05 inches to a depth of 60 inches of soil, the lime content from 0 to 6.2%, the pH from 5.67 to 8.34, and the average pH per profile from 5.91 to 8.03.

In about one-quarter of the plots, the soil was comparatively heavy and at least 60 inches deep; in about one-half it was light and only 24 inches or less in depth; and in the remainder it ranged between these two groups in texture and depth. The deeper, heavier soils had, on the average, higher moisture holding capacities, more lime, and higher pH values than the lighter, shallower soils. In the deeper soils, both the lime content and the pH increased with depth. There was no evidence of true hardpan or of excess moisture in the soil in any of the plots selected for this study.

The more pertinent of the coefficients of correlation revealed the following trends: (1) The heavier and deeper the soil (as measured by the total moisture holding capacity to a depth of 60 inches), the higher was the average pH, the more vigorous were the trees, the less was the degree of biennial bearing, the higher was the total yield, and the higher was the yield of high quality fruit. (2) The higher the pH, the higher was the total yield. However, when the effects of moisture holding capacity were eliminated by partial correlations, there was found to be no direct relationship between pH and yield. There was no relationship found between pH on the one hand and tree vigour and biennial bearing on the other hand.

It is concluded that the deeper, heavier soils in the plots chosen showed better promise for good tree performance than did the lighter, shallower soils. Just what factors entered into this effect were not determined.

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APPENDIX

TABLE 3.—McINTOSH PLOT TREE DATA

(Plot averages)

1	2	3	4	5	6	7
Plot No.	No. of trees	Trunk-ground ratio	Terminal length	Biennial bearing index	Total yield*	Profitable yield*
			cm.		boxes	boxes
P2†	5	.27	28.1	70	1227	1111
P3	5	.29	29.1	66	1079	1058
P4	5	.29	28.0	66	1051	977
P1	3	.27	28.9	69	987	891
P9	5	.37	28.4	38	1813	1525
P10	1	.33	32.3	35	1950	1531
P5	5	.49	38.7	19	1477	942
P7	3	.39	25.9	56	1123	936
P6	4	.37	26.7	48	1007	912
S12	5	.32	19.3	93	768	687
S10	5	.38	26.2	61	716	671
T2	4	.48	28.2	100	1001	842
T3	4	.43	32.4	85	1235	1084
T6	5	.26	29.1	96	1328	1131
T7	5	.26	29.8	83	1334	1110
T8	5	.40	28.7	25	1435	1242
T9	1	.34	22.6	58	1264	1165
K2	4	.31	16.4	26	1339	1230
K6	3	.25	22.7	24	1413	1246
K21	5	.31	21.1	65	1135	1011
K7	5	.32	26.0	57	1080	978
K9	5	.37	21.0	76	924	861
K27	5	.36	16.2	76	781	739
K16	5	.33	24.4	67	1174	1082
K10	4	.34	22.9	37	1153	1066
K54	5	.33	26.1	16	1420	1110
K11	3	.22	27.2	47	1254	998
K12	5	.28	25.4	42	1349	1144
K13	5	.29	25.8	52	1326	1158
K14	5	.26	25.2	51	1282	1103
K15	3	.25	24.7	47	914	772
K46	3	.26	28.1	47	1139	928
K51	3	.31	26.7	61	1083	893
K22	5	.28	27.7	67	1321	1206
K25	5	.38	28.2	37	1534	1342
K24	3	.37	25.5	56	1509	1360
K49	4	.28	30.4	38	1350	1013
K8	5	.32	22.0	32	1660	1433
K48	5	.26	30.5	56	1406	1157
B29	5	.25	22.8	45	1080	977
B30	5	.27	32.4	59	1170	978
B31	4	.27	23.5	45	1165	1031
B1	5	.37	22.5	64	1092	935
B34	5	.39	25.9	83	1070	929
B33	5	.37	19.7	48	1413	1307
B38	5	.42	19.2	57	1159	1084
B36	5	.40	26.1	87	880	844
B37	5	.36	28.0	72	896	838
G42	5	.31	25.7	23	1602	1328
G50	5	.42	26.6	71	858	849
G26	5	.33	24.4	15	1576	1313

* The total and profitable yield are expressed in terms of loose bushel boxes per acre, adjusted for differences in size of tree.

† The arrangement of the plot numbers is by position in the field, rather than by number.

APPENDIX

TABLE 3.—McINTOSH PLOT TREE DATA—*Continued*

(Plot averages)

1	2	3	4	5	6	7
Plot No.	No. of trees	Trunk-ground ratio	Terminal length	Biennial bearing index	Total yield*	Profitable yield*
			cm.		boxes	boxes
G18	5	.38	25.7	61	1032	768
G17	5	.29	19.6	76	978	880
G19	5	.34	22.1	31	1144	1023
G20	5	.30	20.2	28	1216	1147
W2	5	.32	19.5	26	1060	953
W7	5	.29	28.0	16	996	822
W6	5	.29	23.8	47	909	852
W5	5	.31	18.4	28	1261	1030
W9	5	.37	29.5	19	1583	1224
W8	5	.34	27.0	12	1486	1213
W10	4	.48	25.4	30	1391	1222
O14	5	.32	23.1	20	1274	1134
O17	5	.34	25.1	72	1000	896
O15	5	.25	33.4	28	1181	966
O19	5	.36	14.6	57	927	768

* The total and profitable yield are expressed in terms of loose bushel boxes per acre, adjusted for differences in size of tree.

† The arrangement of the plot numbers is by position in the field, rather than by number.

TABLE 4.—McINTOSH PLOT SOILS DATA

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
P2	0– 8	0.0	3.58	2.38	6.85	0.0
	8–24	0.0	3.48	4.64	7.88	2.1
	24–60	0.0	3.43	10.29	8.08	5.2
	0–60			17.31‡	7.60‡	
P3	0– 8	0.0	3.63	2.52	6.28	0.0
	8–24	0.0	3.32	4.43	7.47	0.1
	24–60	0.0	3.03	9.09	8.13	3.9
	0–60			16.04	7.29	
P4	0– 8	0.0	3.52	2.34	6.36	0.0
	8–24	0.0	3.31	4.41	7.75	0.6
	24–60	0.0	3.43	10.29	8.13	5.4
	0–60			17.04	7.41	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
P1	0– 8	0.0	3.59	2.39	7.61	1.4
	8–24	0 0	3.43	4.57	8.19	5.2
	24–60	0.0	3.10	9.30	8.29	2.8
	0–60			16.26	8.03	
P9	0– 8	0.0	3.22	2.15	7.13	0.0
	8–24	0.0	3.32	4.43	7.89	0.1
	24–60	0.0	3.69	11.07	8.19	4.9
	0– 8			17.65	7.74	
P10	0– 8	0.0	2.96	1.97	7.40	0.0
	8–24	0.0	2.83	3.87	7.79	0.0
	24–60	0.0	3.50	10.50	8.14	4.5
	0–60			16.34	7.78	
P5	0– 8	0.0	3.45	2.30	6.67	0.0
	8–24	0.0	3.28	4.37	7.93	1.6
	24–60	0.0	3.05	9.15	8.33	3.0
	0–60			15.82	7.64	
P7	0– 8	21.9	2.50	1.67	6.68	0.0
	8–24	0.0	2.85	3.67	6.73	0.0
	0–24			5.34	6.70	
P6	0– 8	0.0	3.37	2.25	6.68	0.0
	8–24	29.4	1.98	2.64	6.35	0.0
	0–24			4.89	6.51	
S12	0– 8	0.0	2.96	1.97	6.93	0.0
	8–24	33.7	1.66	2.21	8.09	0.1
	0–24			4.18	7.51	
S10	0– 8	18.0	2.24	1.49	6.78	0.0
	8–24	40.1	1.42	1.89	6.64	0.0
	0–24			3.38	6.71	
T2	0– 8	8.0	2.94	1.96	6.11	0.1
	8–36	19.4	2.55	5.95	8.06	3.3
	0–36			7.91	7.08	
T3	0– 8	7.9	2.53	1.69	6.15	0.0
	8–24	38.4	1.52	2.03	7.31	0.0
	0–24			3.72	6.73	
T6	0– 8	20.2	2.65	1.77	7.64	0.0
	8–24	35.6	1.77	2.36	7.48	0.0
	0–24			4.13	7.56	
T7	0– 8	33.6	2.19	1.46	7.39	0.0
	8–24	57.4	1.21	1.61	7.28	0.0
	0–24			3.07	7.33	
T8	0– 8	4.3	3.10	2.07	7.27	0.0
	8–30	28.2	2.27	4.16	7.86	0.6
	0–30			6.23	7.56	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.
M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
T9	0– 8	2.2	2.44	1.63	7.22	0.0
	8–24	18.5	1.86	2.48	7.29	0.0
	0–24			4.11	7.25	
K2	0– 8	0.0	2.87	1.91	6.10	0.0
	8–20	26.7	1.95	1.95	6.57	0.0
	0–20			3.86	6.33	
K6	0– 8	0.0	3.00	2.00	6.35	0.0
	8–18	36.8	1.58	1.32	6.77	0.0
	0–18			3.32	6.56	
K21	0– 8	0.0	2.73	1.82	6.75	0.0
	8–26	0.0	2.54	3.81	6.74	0.0
	0–26			5.63	6.74	
K7	0– 8	0.0	2.96	1.97	6.27	0.0
	8–24	0.0	2.85	3.80	6.67	0.0
	24–44	0.0	2.95	4.91	7.84	0.5
	0–44			10.68	6.93	
K9	0– 8	0.0	3.08	2.06	6.06	0.0
	8–24	4.1	2.75	3.67	6.90	0.0
	24–35	13.0	2.65	2.43	8.34	0.9
	0–35			8.16	7.10	
K27	0– 8	0.0	3.35	2.23	6.61	0.0
	8–40	61.7	0.95	2.25	6.66	0.0
	0–40			4.45	6.63	
K16	0– 8	0.0	3.22	2.14	6.70	0.0
	8–24	0.0	3.20	4.27	6.96	0.0
	24–54	0.0	3.73	9.34	7.98	3.0
	0–54			15.75	7.21	
K10	0– 8	8.7	2.76	1.84	6.73	0.0
	8–27	54.7	1.16	1.84	6.49	0.0
	0–27			3.68	6.61	
K39	0– 8	62.5	1.23	0.82	6.56	0.0
	8–29	51.1	1.25	2.19	6.30	0.0
	0–29			3.01	6.43	
K53	0– 8	32.8	2.44	1.63	6.04	0.0
	8–28	62.3	1.09	1.82	5.98	0.0
	0–28			3.45	6.01	
K54	0– 8	9.2	2.86	1.91	6.40	0.0
	8–25	64.0	0.94	1.33	6.36	0.0
	0–25			3.24	6.38	
K11	0– 8	12.8	2.89	1.93	6.46	0.0
	8–22	59.4	1.01	1.18	6.36	0.0
	0–22			3.11	6.41	

* The M.C.F. and lime content have been adjusted for the per cent gravel.
† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.
M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.
‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
K12	0– 8	12.0	2.74	1.83	5.87	0.0
	8–23	53.8	1.12	1.40	6.34	0.0
	0–23			3.23	6.10	
K13	0– 8	11.8	2.84	1.89	6.30	0.0
	8–25	46.4	1.26	1.78	6.34	0.0
	0–25			3.67	6.32	
K14	0– 8	11.0	2.78	1.85	5.99	0.0
	8–24	47.4	1.25	1.67	6.36	0.0
	0–24			3.52	6.17	
K15	0– 8	27.2	2.40	1.60	6.66	0.0
	8–23	58.0	1.07	1.34	6.46	0.0
	0–23			2.94	6.56	
K46	0– 8	9.4	2.74	1.83	6.27	0.0
	8–22	46.4	1.29	1.50	6.51	0.0
	0–22			3.33	6.39	
K51	0– 8	9.9	2.79	1.86	5.67	0.0
	8–21	45.1	1.32	1.43	6.15	0.0
	0–21			3.29	5.91	
K17	0– 8	0.0	3.50	2.33	6.64	0.6
	8–24	0.0	3.73	4.97	6.54	0.0
	24–48	0.0	4.12	8.14	7.80	2.6
	0–48			15.44	6.99	
K18	0– 8	0.0	4.18	2.78	6.72	0.0
	8–24	0.0	4.45	5.94	7.74	2.7
	24–60	0.0	4.22	12.66	8.23	3.3
	0–60			21.38	7.56	
K22	0– 8	13.2	2.65	1.77	5.83	0.0
	8–22	50.4	1.60	1.87	6.14	0.0
	0–22			3.64	5.98	
K44	0– 8	14.0	2.86	1.91	5.78	0.0
	8–22	63.2	0.97	1.13	6.10	0.0
	0–22			3.04	5.94	
K25	0– 8	0.0	4.08	2.72	6.53	0.0
	8–24	0.0	4.58	6.10	7.35	1.4
	24–60	0.0	4.58	13.64	7.78	2.3
	0–60			22.46	7.22	
K24	0– 8	0.0	2.78	1.85	6.54	0.0
	8–24	19.3	1.97	2.62	6.64	0.0
	24–57	16.1	2.58	7.09	8.02	0.7
	0–57			11.56	7.07	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
K49	0– 8	0.0	4.32	2.88	6.69	0.0
	8–24	0.0	4.62	6.16	7.95	3.6
	24–60	0.0	4.67	14.01	7.63	2.0
	0–60			23.05	7.42	
K8	0– 8	0.0	3.84	2.56	7.02	0.0
	8–24	0.0	4.00	5.44	7.64	2.5
	24–60	0.0	4.22	12.66	7.96	2.2
	0–60			20.66	7.54	
K48	0– 8	0.0	4.26	2.84	6.63	0.0
	8–24	0.0	4.35	5.91	7.65	1.7
	24–60	0.0	4.35	13.05	8.22	3.2
	0–60			21.80	7.50	
B29	0– 8	0.0	2.85	1.90	6.93	0.0
	8–30	0.0	2.60	4.76	7.10	0.0
	0–30			6.66	7.01	
B30	0– 8	0.0	2.92	1.95	6.21	0.0
	8–27	0.0	2.68	4.25	6.68	0.0
	0–27			6.20	6.44	
B31	0– 8	0.0	2.92	1.95	5.82	0.0
	8–27	0.0	2.70	4.28	6.78	0.0
	0–27			6.23	6.30	
B1	0– 8	0.0	3.05	2.04	6.21	0.0
	8–24	0.0	2.88	3.92	6.69	0.0
	24–57	0.0	3.23	8.88	8.01	0.9
	0–57			14.84	6.97	
B34	0– 8	5.3	2.58	1.72	6.47	0.0
	8–24	7.1	2.65	3.60	6.58	0.0
	24–38	43.0	1.34	1.56	6.65	0.0
	0–38			6.88	6.57	
B33	0– 8	0.0	2.70	1.80	6.60	0.0
	8–24	0.0	2.65	3.60	6.44	0.0
	24–36	0.0	2.38	2.38	6.93	0.0
	0–36			7.78	6.66	
B38	0– 8	0.0	2.98	1.99	6.56	0.0
	8–27	0.0	2.60	4.11	6.32	0.0
	0–27			6.10	6.44	
B36	0– 8	0.0	3.02	2.01	6.02	0.0
	8–31	37.4	1.67	3.20	7.19	0.0
	0–31			5.21	6.60	
B37	0– 8	0.0	3.12	2.08	6.12	0.0
	8–27	31.1	1.88	2.98	6.62	0.0
	0–27			5.06	6.37	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
G42	0– 8	0.0	3.27	2.18	6.95	0.0
	8–24	0.0	3.03	4.12	6.63	0.0
	24–60	0.0	2.73	8.19	8.18	1.4
	0–60			14.49	7.25	
G50	0– 8	0.0	2.76	1.84	5.95	0.0
	8–24	0.0	2.38	3.24	6.91	0.0
	24–60	0.0	2.70	8.10	8.24	0.3
	0–60			13.18	7.03	
G26	0– 8	0.0	2.92	1.95	6.94	0.0
	8–24	0.0	2.82	3.70	8.12	0.1
	24–60	0.0	2.73	8.19	8.23	0.2
	0–60			13.84	7.76	
G18	0– 8	9.9	2.37	1.58	6.36	0.0
	8–24	18.9	2.03	2.76	6.79	0.0
	24–44	22.5	2.32	3.87	7.73	0.1
	0–44			8.21	6.96	
G17	0– 8	40.0	2.06	1.37	7.02	0.0
	8–24	42.2	1.66	2.26	7.31	0.0
	24–40	24.8	2.56	3.41	8.21	1.5
	0–40			7.04	7.51	
G19	0– 8	0.0	4.10	2.73	7.12	0.0
	8–24	0.0	3.67	4.99	7.60	1.0
	24–57	0.0	3.46	9.52	8.12	6.2
	0–57			17.24	7.61	
G20	0– 8	0.0	4.08	2.72	7.15	0.0
	8–24	0.0	4.20	5.71	7.68	2.7
	24–60	0.0	4.20	12.60	7.92	4.0
	0–60			21.03	7.58	
W2	0– 8	0.0	3.82	2.54	6.56	0.0
	8–24	0.0	4.10	5.58	7.25	0.0
	24–48	0.0	3.68	7.36	7.93	0.9
	0–48			15.48	7.25	
W7	0– 8	0.0	2.38	1.59	6.11	0.0
	8–30	5.2	2.26	4.15	6.64	0.0
	0–30			5.74	6.37	
W6	0– 8	8.5	2.26	1.51	6.45	0.0
	8–24	26.1	1.77	2.41	6.50	0.0
	0–24			3.92	6.47	
W5	0– 8	3.5	2.54	1.69	6.50	0.0
	8–24	20.0	1.88	2.56	6.80	0.0
	0–24			4.25	6.65	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Concluded*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
W4	0– 8	0.0	2.53	1.69	6.13	0.0
	8–24	0.0	2.48	3.37	6.62	0.0
	24–60	3.1	2.13	6.39	6.95	0.0
	0–60			11.45	6.57	
W9	0 –8	0.0	3.92	2.61	6.63	0.0
	8–24	0.0	4.12	5.60	6.80	0.0
	24–60	0.0	4.05	12.15	8.01	3.2
	0–60			20.36	7.15	
W8	0– 8	0.0	2.82	1.88	6.50	0.0
	8–24	10.4	2.46	3.35	6.81	0.0
	24–52	0.0	3.83	8.94	8.27	2.5
	0–52			14.17	7.19	
W10	0– 8	0.0	3.18	2.12	6.57	0.0
	8–24	0.0	2.68	3.64	6.42	0.0
	24–60	0.0	3.20	9.60	8.24	0.0
	0–60			15.36	7.08	
O14	0– 8	0.0	3.28	2.18	6.63	0.0
	8–33	8.0	2.65	5.52	7.79	0.0
	0–33			7.70	7.21	
O17	0– 8	6.8	2.73	1.82	6.44	0.0
	8–24	8.9	2.41	3.28	6.57	0.0
	0–24			5.10	6.50	
O15	0– 8	37.9	1.58	1.05	6.33	0.0
	8–24	30.4	1.76	2.40	6.20	0.0
	0–24			3.45	6.26	
O18	0– 8	27.3	1.93	1.29	7.01	0.0
	8–24	40.5	1.70	2.31	7.15	0.0
	0–24			3.60	7.08	
O19	0– 8	43.8	2.19	1.46	7.42	0.0
	8–24	53.3	1.33	1.81	7.40	0.1
	0–24			3.26	7.41	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.
M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

III. ROOT DISTRIBUTION[1]

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This paper is the third in a series reporting the findings of an investigation into the effects of certain factors on apple tree performance in the Okanagan Valley in British Columbia. The first paper (21) dealt with tree size, tree vigour, biennial bearing and distance of planting; and the second paper (22) dealt with soil depth, moisture holding capacity and pH. This present paper reports findings with respect to root distribution, and its relationship to certain soil characteristics and soil treatments on the one hand and to tree performance on the other hand.

The findings from three separate studies are combined in this report: (*a*) Studies of root distribution as affected by soil texture and depth and by certain cultural treatments, made in 1933. (*b*) Similar studies made in 1936. Most of the work in 1933 and 1936 was done in the Dominion Experimental Substation orchard at Kelowna. (*c*) Studies of root distribution in the McIntosh plots used as the general basis for this series of papers. These studies were made in 1939 and 1940.

Comprehensive reviews of the literature on the root growth of fruit trees have already been published (3, 12, 24), and it does not appear necessary to present a further review at this time.

PROCEDURE

In the 1933 studies, trenches were dug beside selected trees in a series of plots receiving differential irrigation, fertilizer, and root-pruning treatments, and beside trees in soil differing in depth and texture, to a total of 25 trenches. The procedure used in each case was to dig a trench 2 feet wide starting at a point 5 feet from the trunk of a mature tree, and proceeding outward to the centre of one of the surrounding tree squares, usually a distance of 16 feet. In most cases, digging was discontinued when the roots petered out; but in no case was a trench dug deeper than 8 feet, even though some roots were still in evidence at that depth. The walls of the trench were smoothed down with the shovel, scarified lightly with a rake to reveal the root tips, and divided into foot squares with string and nails. The soil variations were mapped, on the basis of visual examination only, and designated as horizons A, B and C in the usual way (9). The apple roots exposed were also mapped, in accordance with the following diameter classes: (1) less than $\frac{1}{8}$ inch, (2) $\frac{1}{8}$ to $\frac{1}{4}$ inch, (3) $\frac{1}{4}$ to $\frac{1}{2}$ inch, (4) $\frac{1}{2}$ to 1 inch, (5) over 1 inch.

In 1936, 13 trenches were dug beside trees in some of the same plots as in 1933. The procedure was similar, except that digging was started at 3 feet from the trunk.

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In 1939 and 1940, 13 trenches were dug in the irrigation and fertilizer plots on the Substation at Kelowna, and 50 trenches were dug beside mature trees in the McIntosh plots (21) in grower owned orchards. The procedure used was to start 5 feet from the trunk and dig outward just far enough to map a 4-foot length along the side of the trench. The 2-foot face nearest the tree and one or both side walls of the trench were divided into 6-inch squares with string, and the soil horizons and root distribution were mapped, as in 1933. (The area covered is illustrated in Figure 6).

As noted in a previous paper (21), groups of mature McIntosh trees were selected in grower owned orchards in the Okanagan Valley in 1937, with 5 trees or less to a group. For want of a better term, the orchard area containing each group of trees was called a "plot." In selecting these plots, a deliberate attempt was made to include a wide variation in soil texture, soil depth, and cultural treatments. The relationships of soil texture and depth to tree performance in 75 of the plots have already been reported (22). It was in these plots that the 50 trenches beside mature McIntosh trees were dug in 1939 and 1940. They were located as follows: 26 in East Kelowna, 9 in Rutland, 2 in Glenmore, 8 in Winfield, and 5 in Oyama.

Although there was a wide variation among plots in soil depth and texture, within any one plot the soil was almost always reasonably uniform. The degree of uniformity within each plot was determined prior to excavating the trench, by making auger borings around each tree, and the location finally selected for the trench was always one that appeared to represent both the tree and the plot fairly. Because of this, it was felt that the root counts could reasonably be compared not only with the records on the tree adjacent to the trench, but also with the averages of all trees in the plot.

In the first paper of this series (21), the methods of obtaining the tree records in the McIntosh plots and of conducting the statistical analyses on them were described. For the purpose of correlating with soil characteristics, the tree data were tabulated as plot averages in the second paper (22) of the series. These same plot averages are used in this paper for comparison with root distribution. In the second paper, also, the procedures used in sampling the soil and in making certain chemical and physical analyses were described, and the data thus obtained were presented. These data are likewise used in this paper for comparison with root distribution data. Reference is made under "Results" to soil anaylses for phosphorus and potassium. These analyses will be reported in detail in a subsequent paper.

In order to study the relationships of root distribution to soil characteristics and to tree performance, it was considered desirable to express the root distribution in mathematical form. As a basis for this expression, the smaller or "feeding" roots were considered to be the most suitable. Accordingly, all roots less than $\frac{1}{8}$ inch in diameter were counted from the profile maps, and were tabulated by depths and by distance from the tree. In calculating the totals per tree, only those roots were used that lay between the surface and 60 inches in depth, and in the 6 feet of pit face represented by 2 feet at the end nearest the tree and 4 feet from this end outward along one side wall of the trench. The results from the 50 McIntosh plots are presented in Table 3 in the Appendix. These results are used in all of the root correlations presented in this paper.

RESULTS

General Root Distribution

From point to point around a tree, the concentration of fibrous roots was found to be somewhat variable. For the most part, however, this variability did not appear great enough to invalidate the use of a single trench to represent the tree as a whole. Occasionally, quite wide variability in root concentration around a tree was encountered. In some cases it was obviously due to injury to large roots by the discs or furrower; in other cases it appeared to be associated with changes in soil depth and texture. Such trees were of course avoided in making trench studies of the roots.

In contrast with the comparative uniformity from point to point around the tree was the lack of uniformity in other directions. In many cases, there was considerable variability in concentration of fibrous roots with increasing depth in the soil and with increasing distance from the tree. This can be seen from Figures 5 and 6 and from the data in Table 3. The lack of uniformity was usually much less marked with older trees than with younger trees.

In spite of this lack of uniformity in root distribution, observation and counts revealed that root distribution was definitely affected by certain factors. In general, the older and the larger the tree, the greater was the concentration of fibrous roots farther out from the trunk and deeper down in the soil; and as a result, the greater was the total number of fibrous roots per tree. Although the trees in the McIntosh plots were all classed as "mature," there seemed to be some relationship among them between tree size and root concentration, as evidenced by the correlation shown in Table 1 between trunk circumference and root concentration in the 6- to 24-inch layer.

TABLE 1.—SOME CORRELATIONS BETWEEN ROOT CONCENTRATION AND OTHER FACTORS

Two factors correlated		Coefficient of correlation
Fibrous roots,*6–24 inches	Trunk circumference	+ .173 (NS)
Fibrous roots, 6–12 inches	Depth of soil	+ .010 (NS)§
Fibrous roots, 6–24 inches	M.H.C.,† 8–24 inches	+ .153 (NS)
Fibrous roots, 0–60 inches	M.H.C., 0–60 inches	+ .513 (HS)
Fibrous roots, 6–24 inches	pH, 8–24 inches	+ .295 (S)
Fibrous roots, 6–24 inches	pH, 8–24 inches‡	+ .254 (NS)
Fibrous roots, 6–24 inches	P content, 8–24 inches	+ .107 (NS)
Fibrous roots, 0–60 inches	P content, 0–60 inches	− .037 (NS)
Fibrous roots, 6–24 inches	K content, 8–24 inches	+ .169 (NS)
Fibrous roots, 0–60 inches	K content, 0–60 inches	+ .390 (HS)
Fibrous roots, 0–60 inches	K content, 0–60 inches‡	− .145 (NS)
Fibrous roots, 0–60 inches	Terminal length	+ .076 (NS)
Fibrous roots, 0–60 inches	Yield per acre	+ .127 (NS)
Fibrous roots, 6–24 inches	Yield per acre	+ .069 (NS)

* Fibrous roots = roots less than ⅛ inch in diameter.
† M.H.C. = total moisture holding capacity per stated depth, expressed in inches of water.
‡ In these two correlations, the effects of the M.H.C. have been eliminated.
§ NS = non-significant, with odds less than 19 : 1.
S = significant, with odds between 19 : 1 and 99 : 1.
HS = highly significant, with odds greater than 99 : 1

As would be expected, there was a tendency for the concentration of fibrous roots to decrease with greater distance from the trunk. This held true even within the 4-foot distance mapped in the McIntosh plots. When the percentages of fibrous roots at each distance were averaged for the 50 trenches, the results were as follows:

5 feet from trunk (average of two feet of pit face)	22.8%
5 to 6 feet from trunk	21.9%
6 to 7 feet from trunk	19.9%
7 to 8 feet from trunk	18.7%
8 to 9 feet from trunk	16.7%
	100.0%

The degree to which the roots were distributed in the surface horizon appeared to depend mostly on cover crop, cultivation, and irrigation practices. With sod grasses, the cover crop roots tended to exclude the apple roots from the top few inches. With leguminous cover crops, this effect was not so marked. Deep cultivation likewise reduced the number of roots in the surface horizon. The roots came closest to the surface under a cultural system involving frequent light cultivations (spring, midsummer and fall) and frequent irrigations. In some cases, the root concentration in the top foot appeared by visual examination to be greater where the solum (A plus B horizons) was shallower, but this was not borne out by a correlation between the soil depth and the number of fibrous roots in the 6- to 12-inch layers of the 50 plots (Table 1). In almost every case, the greatest concentration of fibrous roots was found between the depths of 6 and 24 inches. The largest roots were usually encountered between the depths of 6 and 18 inches.

The greatest depth of rooting depended primarily on the depth of the solum. In most of the plots the soil was underlain at depths of less than 5 feet by a mixture of clear sand and gravel or by clear sand alone.

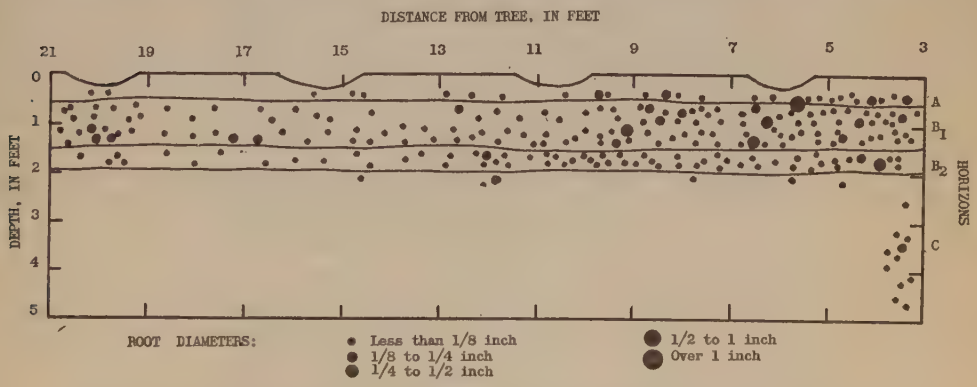

FIGURE 1. Root distribution along one wall of a pit 5 feet deep, dug radially 3 to 21 feet from tree C5 in the Substation orchard at Kelowna. The soil is a shallow phase of the Rutland sandy loam series (4), and is typical of many of the 50 McIntosh plots. It appears to be too shallow for maximum yields. The soil in the surface six inches was pretty well filled with grass roots. Some of the apple roots in the outer part of the pit were from neighbouring trees. These trees were about 21 years old. Each of the smallest dots in the chart represents five fibrous roots, the other dots one root apiece. The soil horizons are as follows: A—dark loamy sand, B_1—loamy sand, B_2—loamy sand and gravel, C—mixture of coarse sand, gravel and stones.

The roots penetrated this "parent" horizon in varying degree, the distance depending on a number of factors. For the most part, the penetration was not over 1 foot. Directly under the tree, however, the penetration was usually much greater than this; and wherever decaying pine roots descended into the subsoil, apple roots followed them down for some distance, often as far as 8 feet or more from the surface. In the deeper soils, the roots were found to grow down to depths of at least 8 feet at 3 feet from the trunk, and to lesser depths out farther from the trunk. With the older trees in deep soils, the whole soil mass was usually permeated with roots to a depth of at least 6 feet. It should be noted that in the original selection of the McIntosh plots, those areas in the Valley that were known to be subject to seepage conditions were avoided; hence no difficulty was encountered from excess water.

FIGURE 2. A pit face in Plot K54. This is a shallow phase of the Rutland sandy loam series (4). The C horizon of coarse sand, gravel and stones is typical of many of the orch ards in the Okanagan Valley.

Characteristic types of root distribution are illustrated in Figures 1 to 5. The distribution of the roots in shallow soils is shown in Figures 1 and 2. These are typical of a high percentage of the plots covered in this investigation. The general shape of the root system in a shallow soil can

FIGURE 3. In a shallow soil, the roots of mature fruit trees tend to be shallow and spreading, with no evidence of a definite tap root.

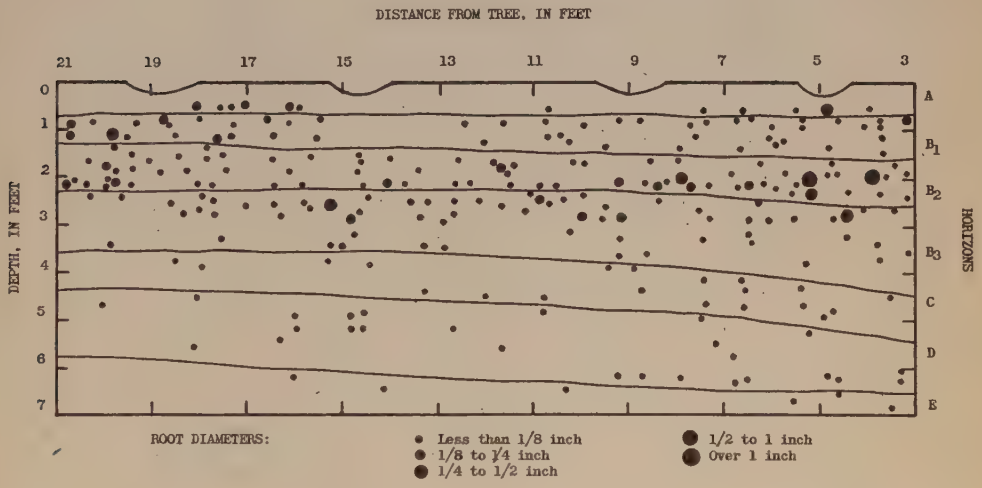

FIGURE 4. Root distribution along one wall of a pit 7 feet deep, dug radially 3 to 21 feet from tree BB23 in the Substation orchard at Kelowna. This tree is near the bottom of a hollow, and the soil is comparatively deep, well wetted, and well drained. The soil is a deep phase of the Rutland sandy loam series (4), and is well adapted to tree fruits. As indicated in the diagram, the pit was dug at right angles to the furrows. Some of the roots in the outer part were from neighbouring trees. The trees were about 21 years old. Each of the smallest dots in the chart represents five fibrous roots, and the other dots one root apiece. The soil horizons are as follows: A—dark loamy sand, B_1—dark sandy loam, B_2—medium sand, B_3—medium sand with dark concretions, C—medium to fine sand, D—silty loam, E—coarse sand.

also be seen in Figure 3. In no case has there been any evidence of a distinct tap root. The distribution of the roots in a deep, sandy loam soil is illustrated in Figure 4, and that in a deep, heavy soil in Figure 5.

Effects of Certain Soil Characteristics

A closer relationship was found between soil texture and root concentration within the one profile than between profiles. In most of the plots, where the soil tended to be sandy, those horizons containing the greater amounts of colloid usually contained the greater concentrations of fibrous roots. Where the soil was heavy, an intervening sandy horizon usually contained fewer roots. An example of this is shown in Figure 6. On the other hand, in the deep, heavy soils studied, occasional narrow horizons were encountered consisting of a tightly packed, laminated mixture high in clay and containing only a few roots (Figure 5). In only two cases was this laminated layer found to be of sufficient thickness to prevent the passage of roots. This was the closest approach to a "claypan" condition that was encountered.

To determine the relationship of soil texture to root concentration between profiles, the number of fibrous roots in the 6- to 24-inch layers of the 50 McIntosh plots was correlated with the moisture holding capacity of the 8- to 24-inch layers. The coefficient of correlation (+ 0.153, Table 1) was non-significant, but still indicated the possibility of greater root concentrations in the heavier soils. Observation indicated that when

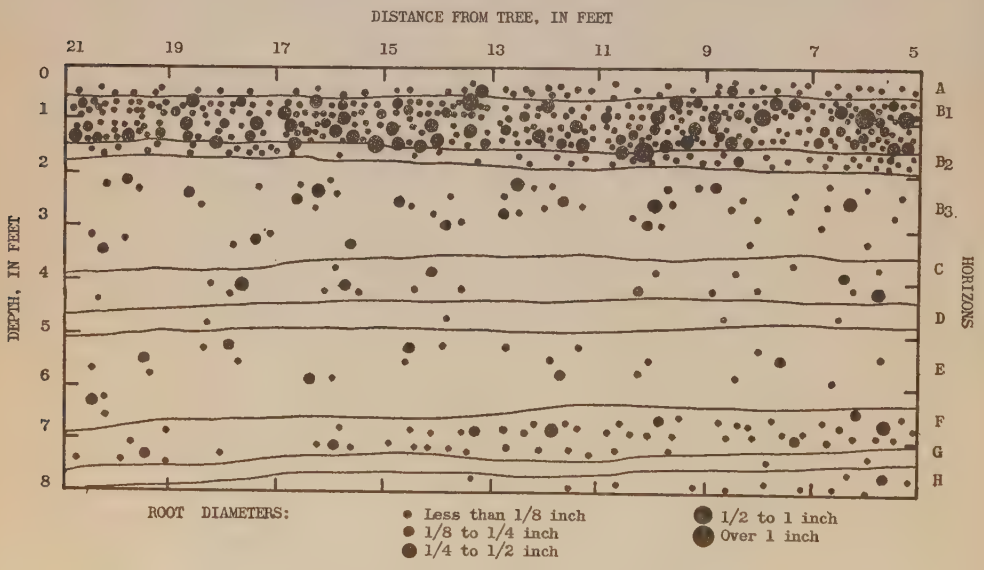

FIGURE 5. Root distribution along one wall of a pit 8 feet deep, dug radially 5 to 21 feet from a tree in Plot K18. The soil is a deep phase of the Glenmore clay series (4). Where not subject to excess seepage, this soil is well adapted to tree fruits. The trees in this plot were about 40 years old. Each of the smallest dots in the chart represents five fibrous roots, the other dots one root apiece. The soil horizons are as follows: A—dark clay loam, B_1—friable clay loam, B_2—lumpy clay loam, B_3—clay loam mixed with sand, gravel, stones and lime, C—clay loam with some lime, D—dark laminated clay, E—uniform clay loam, F—silt loam and lime, quite friable, G—laminated clay, H—clay loam.

other things were equal, the greatest concentration of fibrous roots at any one depth could be expected in a soil moderately heavy in texture, but containing sufficient sand for reasonably good permeability. When the soil texture and soil depth were both taken into account, by correlating the total number of fibrous roots per profile with the total moisture holding capacity, the result was positive and highly significant (+ 0.513). In other words, there was a strong tendency for a larger total number of fibrous roots to be present in the heavy, deep soils than in the light, shallow soils.

No adverse effect of lime in the B horizon was noted on root concentration. In fact, in the deeper horizons of the heavier soils, visual examination indicated the root concentration to be greatest in those horizons rich in free carbonate (Figure 5).

To determine the effect of pH on root concentration, the number of fibrous roots in the 6- to 24-inch layer of the McIntosh plots was correlated with the pH of the 8- to 24-inch layer (22). The coefficient was significant (+ 0.295). As noted in the second paper (22) of this series, however, a positive relationship was found between the pH and the moisture holding capacity. When the effects of variations in moisture holding capacity were eliminated, the coefficient was reduced to + 0.254. This is not far

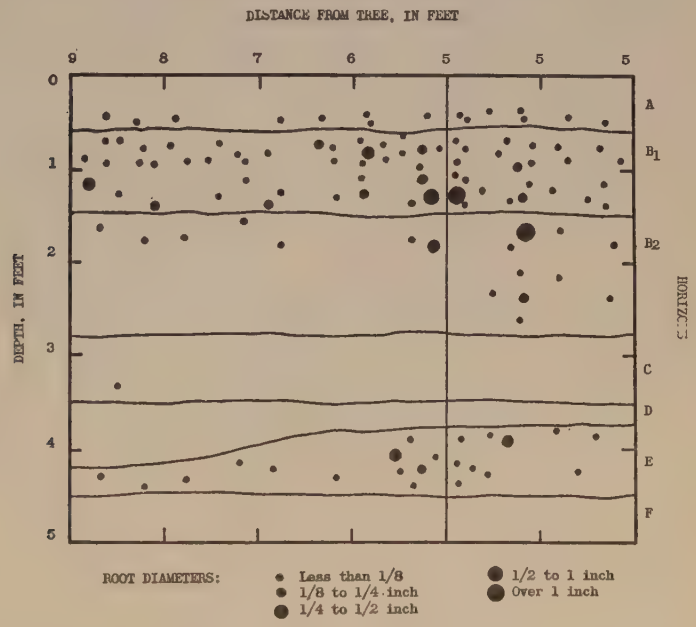

FIGURE 6. Root distribution along one end wall and one side wall of a pit 5 feet deep and 4 feet long, beside a tree in Plot K24. The soil is a shallow phase of the Glenmore clay series (4). This chart illustrates the procedure used in mapping the roots in the 50 McIntosh plots. It also illustrates the extreme variability in root concentrations that was occasionally encountered. Each of the smallest dots in the chart represents five fibrous roots, the other dots one root apiece. The soil horizons are as follows: A—dark clay loam, B_1—silt loam with some gravel, B_2—silt loam, gravel and stones, C—coarse sand and gravel, D—coarse sand, E—compact clay, F—coarse sand.

below "significance." It is quite evident from this that within a pH range of 6.0 to 8.0 there was no adverse effect of the higher pH values on root growth. The evidence is not sufficient, however, to state that the lower pH values did show a detrimental effect.

The only elements determined thus far in the soils of the McIntosh plots have been phosphorus and potassium. The major findings in this connection will be reported in subsequent papers. It is pertinent to note at this time, however, that correlations have been made between the concentration of each of these elements in carbonic acid extracts of the soil on the one hand, and the number of fibrous roots on the other hand. With phosphorus, the coefficients of correlation were quite low and non-significant (Table 1). With potassium, the coefficient for the 6- to 24-inch layer was positive and non-significant, but for the whole profile it was positive and highly significant. Since a high correlation (+ 0.878) has been found in these soils between potassium content and moisture holding capacity, it was suspected that the correlations just noted might actually have been due to relationships with soil texture rather than with soil potassium. That this suspicion was correct is suggested by the fact that when the effects of variations in moisture holding capacity were eliminated from the correlation for the profile as a whole, the coefficient was reduced to a negative value (Table 1). As will be noted in a subsequent paper, there has been evidence of actual P and K deficiencies with apple trees in very few of the soils studied, which may explain the lack of correlation between these two elements and the root counts.

Effects of Certain Cultural Treatments

In the spring of 1931, a number of plots were established in the Dominion Experimental Substation orchard at Kelowna, and differential irrigation, fertilizer and other treatments were started in an attempt to control drought spot and corky core of the apple. The effects of these treatments on the growth and yield of the trees have already been reported (20). In other plots, boric acid and borax in varying amounts have been applied annually since 1936 to a number of mature trees. The effects of these treatments on storage quality of the fruit have been reported by Wilcox and Woodbridge (23). Root examinations, as noted under "Procedure," were made in the first series of plots in 1933, 1936, and 1939, and in the boron series in 1939.

In the irrigation series, all plots were irrigated at the same periods, but received varying amounts of water, from one-quarter as much as necessary for satisfactory tree performance up to twice as much as necessary (20). In all cases, drainage was quite satisfactory. When an insufficient amount of water was applied at each irrigation, the lower horizons in the soil dried out and all the roots in these horizons died. After each irrigation, the fibrous roots grew down into the newly-wetted subsoil for a few inches, then died back again, leaving a dense mat of dead or dying rootlets. In the plot receiving twice as much water as necessary, the fibrous roots in the 6- to 18-inch layer were much more numerous than in the plot receiving just sufficient water. In the former of these two plots, the moisture content never fell far below the moisture holding capacity.

In the fertilizer series of plots, sulphate of ammonia was applied at rates of 0, 6 and 15 pounds per tree annually; superphosphate at rates of 0, 4 and 20 pounds per tree annually; and muriate of potash at rates of 0, 2 and 20 pounds per tree annually (20). An examination of the root concentration and distribution failed to reveal any differences that could be attributed to the fertilizer treatments. If there actually were any effects of the fertilizers on the roots, they were effectively masked by other factors.

Two trees were root-pruned in the spring of 1931, by digging trenches down to the gravelly subsoil, in a circle around each tree at 4 feet from the trunk. The same was done with two trees at 7 feet from the trunk, and with two at 10 feet. The rate at which the new roots extended from the cut ends is indicated in Table 2. The distances shown are the greatest recorded at each period. The examination made in 1939 was the most detailed, hence there was more chance of recording the greatest amount of growth. In all cases, the depth at which the most rapid growth occurred was 8 to 14 inches. The 22-foot growth was made largely along a decaying root killed in the root pruning. This indicates how rapidly roots can grow under favourable conditions.

TABLE 2.—RATE OF GROWTH OF NEW ROOTS, AFTER ROOT PRUNING IN 1931

Radius of root pruning	Distance of new growth		
	1933	1936	1939
feet	feet	feet	feet
4	4	7	22
7	2	4½	11
10	2	3	9

In the boron tests, two trees had received annually 4 pounds of boric acid and 4 pounds of borax, respectively, for four years. In both cases, the foliage had assumed an unhealthy pale appearance, and the fruit was showing breakdown in storage (23). The cover crop was almost all dead from near the trunk out to just beyond the spread of the branches, where the boric acid or borax had been applied. An examination of the apple roots showed that they had all been killed within the area of application down to a depth of about 10 inches with boric acid, and 7 inches with borax. There was also some root killing with the 2-pound applications, but none was observed with applications lighter than this.

Relation to Tree Performance

Correlations were calculated between the number of fibrous roots in each of the 50 McIntosh plots and both terminal length and yield per acre. The results are presented in Table 1 and Figure 7. No relationship was found between the total number of fibrous roots per profile and the terminal length. In view of the high positive correlation between total moisture holding capacity and yield (22), and between total moisture holding capacity and total number of fibrous roots, a high positive correlation might have

been anticipated between the number of fibrous roots and yield. A positive correlation (+ 0.127) was actually obtained, but it was not significant. This lack of significance may have been due to the natural variability in root concentration, as noted above. The best that can be said, however, is that any relationship there may have been between root concentration and yield was largely overshadowed by the effects of other factors.

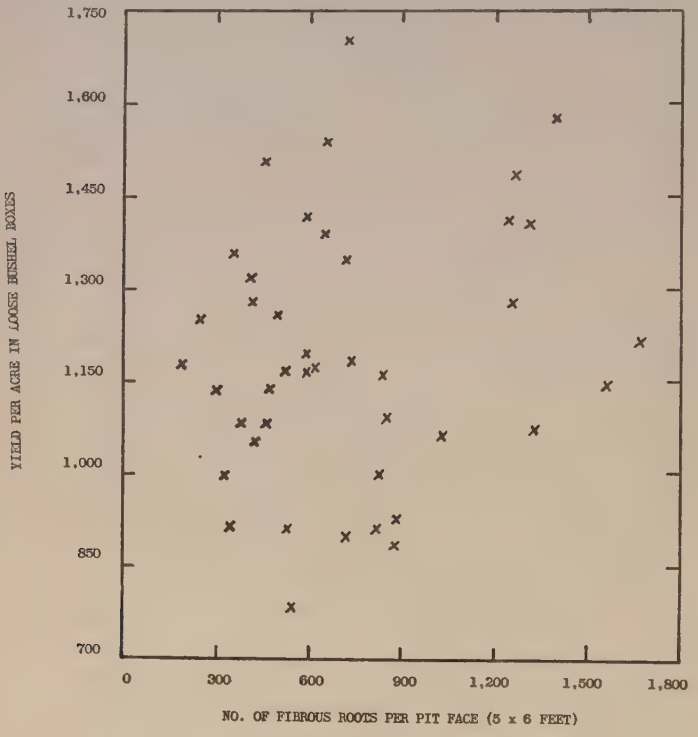

FIGURE 7. Scatter diagram of yield per acre plotted against number of fibrous roots per pit face. Each pit was 5 feet deep. That part of the pit face used consisted of the end nearest the tree (2 feet wide), and a 4-foot length along one side. ($r = +0.127$).

In considering the inter-relationships between yield, moisture holding capacity, and number of fibrous roots, the exceptions to the general trends are of almost as much interest as the trends themselves. In Plot K18 (Table 3), for example, the soil was heavy and deep and the root count was very high, but the yield was low. This appeared to be due primarily to lack of tree vigour, induced by a deficiency of nitrogen. In Plot K25, the soil was heavy and deep, the root count was only medium, but the yield was very high. In Plot B34, the soil was of medium depth, the root count was very high, and the yield was comparatively low. In Plot O19, the soil was light and shallow, the root count was comparatively high, and the yield was low. In Plot K22, the soil was light and shallow and the root count was low, but the yield was comparatively high. In no case, however, were the highest yields associated with very shallow soils or very low root counts. The most important exception to the general trends appears to be the occasional combination of a light, shallow soil with high root concentrations and moderately high yields.

DISCUSSION

In this investigation, only five factors were found to be definitely related to the concentration of fibrous roots in the soil: (1) Depth. The concentration was usually highest between the depths of 6 and 18 inches. (2) Proximity to tree. The closer to the tree (to within at least 5 feet from the trunk), the higher the root concentration. (3) Size of tree. The larger the tree, the greater the root concentration, and the greater the spread and depth of the roots. (4) Soil texture. A moderately heavy loam, containing only sufficient sand or lime to maintain satisfactory permeability, appeared to be the most suitable for the growth of fibrous roots. (5) Soil moisture. A high soil moisture accompanied by good drainage gave the greatest root concentrations in the plots on the Kelowna Substation. Among the factors whose effects were absent, or were too low for measurement with certainty under the variable conditions encountered in the field, were soil pH, phosphorus concentration, potassium concentration, and soil applications of sulphate of ammonia, superphosphate, and muriate of potash.

It is interesting to compare the above findings on the relation of soil texture to apple root concentration with the findings of investigators elsewhere. In deep, well drained profiles in New York, Oskamp and Batjer (9) found higher concentrations of fibrous roots in comparatively heavy soil horizons than in light soil horizons. In shallower profiles subject to excess water, however, better root growth was found in the lighter soil horizons. Sweet (16) in New York obtained similar results to those of Oskamp and Batjer in deep, well drained profiles. Browning and Sudds (1) in West Virginia presented charts showing almost equally good root growth through silty loam and compact clay horizons in the same profiles. Oskamp noted both sandy soil (7) and clay soil (8) horizons too compact for satisfactory root growth. Rogers and Vyvyan (14) in England, Knight (5) in Michigan, and Schuster and Stephenson (15) in Oregon also described heavy clay soils too compact for normal root growth of fruit trees. As already noted, the heavy clay horizons encountered in this investigation were found to prevent root penetration in only two cases. However, penetration has undoubtedly been slower in the heavy soils than in the lighter soils.

It has been assumed in this investigation that in so far as tree performance is concerned, the most important roots are the small fibrous ones; and an attempt has been made to determine the relationships between the relative concentration and total number of fibrous roots on the one hand and tree growth and yield on the other hand. The correlations obtained were all non-significant. This result was somewhat surprising. It was realized (as pointed out by Veatch and Partridge (18) and others) that when there are optimum moisture and nutrient conditions in the soil, a tree can grow and yield satisfactorily with a comparatively small root system. Under optimum conditions in the soil, however, it was anticipated that whether or not the root system was shallow or deep, there would be a very high concentration of fibrous roots in the more favoured horizons (6). This, it was felt, should occur as a result of (1) the direct stimulus of optimum soil conditions on the annual growth and branching of the roots (6, 13, 18), and of (2) the reciprocal effect on the roots of better growth and

health of the top of the tree. Better performance of the top of the tree and greater numbers of fibrous roots should therefore occur together. It is obvious from this investigation that such a relationship does not hold true under all circumstances. For example, in some plots low in nitrogen (K18, O19) the number of fibrous roots was comparatively high but the yield was very low. Although under ordinary circumstances a high concentration of fibrous roots may be considered desirable, it appears that other factors may be of even greater importance in determining tree yields.

It is quite possible that the high concentrations of roots in certain sandy soils and in certain soils low in nitrogen (as noted above), may be attributed in part to the nitrogen relationships. Weaver, Jean and Crist (19) in 1922 reported that applications of nitrogenous fertilizers induced greater branching of roots in the fertilized soil but reduced the extent of root growth. Reid (10) in 1930 found that a somewhat limited supply of nitrogen plus an adequate supply of carbohydrates furnished excellent conditions for root growth. Morris (6) in 1930 reported that apple trees growing in the most fertile soil tested had the shortest roots and the most numerous branches. In this present investigation, it appears that a low supply of nitrogen has in some cases been instrumental in inducing extensive root growth on the one hand but low vigour of the top and low yields on the other hand. This may explain some of the apparent discrepancies already noted (e.g. Plots K18 and O19). In contrast with the findings just quoted, however, it should be noted that some investigators (2, 17) have found an increase in the nitrogen supply to be followed by an increase in both top growth and root growth, the latter increase usually being the lesser of the two.

In the first paper of this series (21), it was reported that the trees occupying less than 900 square feet of ground space bore larger crops of high quality fruit per acre than did those occupying 900 square feet. As already noted in this present paper, the roots gradually fill out the whole volume of soil available, down to depths of at least 8 to 10 feet in a deep soil. This occurs sooner when the trees are planted closer together. The question arises as to whether the crowding of the soil with fibrous roots is automatically followed by a deterioration in tree performance.

Yocum (24) has suggested that in Nebraska, where soil moisture is a limiting factor, the distance apart of planting should be determined in part by the rate of root growth; that is, the more rapid the growth and hence the sooner the soil becomes filled with roots, the further apart the trees should be located. The evidence obtained in this investigation, however, does not point to such a conclusion for irrigated orchards. Some of the highest yielding plots (e.g. K25, K24) consisted of comparatively old trees occupying only 780 square feet of space per tree. In such cases, the continuation of favourable tree performance appears to have been more dependent on a continuation of optimum moisture and nutrient conditions than on the presence of a continuous supply of fresh "rootless" soil.

The oldest trees used in this investigation were in Plot K18. It is of interest to note that the whole block of trees in which this plot was located had deteriorated badly by 1937. The trees were low in both vigour and yield, and it looked as if age and crowding had limited their usefulness.

Since then, however, heavy pruning and fertilizing have brought the orchard area in and adjacent to Plot K18 back into excellent growth and production. The change in root concentration since 1939 has not been investigated, but on the basis of records obtained in other orchards the roots should be more crowded now than they were in 1939.

It has been a common practice, in studying the nutrient requirements of an orchard, to take soil samples from the surface foot only. It is true that in most orchards included in this investigation the greatest concentration of fibrous roots is not far from a depth of 1 foot. It is true also that the highest concentrations of organic matter and of certain essential elements (e.g. N, P, K) are usually found in the surface foot of soil[4]. In the deeper profiles, however, the roots may permeate the soil to depths of at least 8 to 10 feet; and it appears logical to assume that they are absorbing nutrients to some extent wherever they go. A complete picture of the nutrient status of the soil does not appear possible as a result of an examination of the surface foot of soil only.

SUMMARY

Trenches were dug near apple trees receiving a number of different cultural treatments. They were made 2 feet wide, at least 5 feet deep, and extended from 3 or 5 feet out to 21 feet from the trunk. The soil horizons and roots along one wall were mapped. In addition, trenches were dug near trees in 50 of the McIntosh plots used for the apple nutrition studies, and the horizons and roots were mapped on a pit face 6 feet long and 5 feet deep. The fibrous roots (less than $\frac{1}{8}$ inch in diameter) were totalled in these 50 trenches, and were correlated with certain soil factors and with tree performance.

The root concentration and distribution were found to be quite variable, even around individual trees. The concentration of fibrous roots tended, however, to be greater (1) with older trees, (2) closer to the trunk, and (3) between the depths of 6 and 24 inches. A grass sod lessened the number of apple roots in the surface 6 inches. In deep soils, the roots of older trees filled the soil to a depth of at least 8 feet. In shallow soils, underlain by clear sand and gravel, the roots seldom grew down more than a foot into the sandy subsoil, except right under the trees.

In deep, heavy soils, the roots tended to be less concentrated in sandy layers and in heavy, laminated clay layers. In sandy or light loam soils, they tended to be more concentrated in the heavier layers. In the 50 McIntosh plots the total number of fibrous roots per profile was correlated positively with the total moisture holding capacity per profile. No adverse effect of carbonates was noted. Within a pH range of 6.0 to 8.0, the higher pH values were associated with the greater number of roots. The concentrations of available phosphorus and potassium in the soil showed no significant correlation with the numbers of fibrous roots.

Among the treatments studied, heavy watering accompanied by good drainage favoured the growth of fibrous roots. There were no observable effects of applications of sulphate of ammonia, superphosphate, or muriate of potash; but heavy applications of borax and boric acid killed the fibrous roots in the surface soil.

[4] Further data on this will be published in subsequent papers.

No relationship was found between the number of fibrous roots and tree vigour. A positive but non-significant correlation was obtained between the number of fibrous roots and yield. It is concluded that factors other than number of roots were more important in determining tree performance.

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APPENDIX

TABLE 3.—NUMBERS OF FIBROUS ROOTS COUNTED ON WALLS OF TRENCHES IN McINTOSH PLOTS*

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Plot No.	Ave. depth of roots	By depth, in feet†						By distance from tree, in feet‡					Total
		0–½	½–1	1–2	2–3	3–4	4–5	5	5–6	6–7	7–8	8–9	
	inches												
K1	14	62	92	27				33	27	24	34	30	181
K2	19	87	183	76				79	50	61	40	37	346
K6	16	20	169	145				62	108	65	24	13	334
K7	40	14	117	147	104	43		75	74	83	74	43	425
K8	55	7	148	258	171	91	48	134	111	132	107	103	722
K9	28	151	168	175	40			93	104	75	91	78	534
K10	24	117	320	144				133	125	66	76	47	581
K11	14	36	184	17				43	46	29	40	35	237
K14	22	12	252	146				73	86	74	59	45	410
K15	17	41	231	66				55	60	54	59	55	338
K16	48	151	120	112	119	105		102	104	105	96	98	607
K17	34	36	217	276	79			120	93	104	97	73	608
K18	60+	129	229	338	194	117	149	188	196	206	225	153	1156
K21	20	21	166	112				46	37	48	52	69	299
K22	17	182	170	45				56	69	73	75	67	397
K24	60+	71	143	119	24	23	69	97	83	45	55	71	449
K25	51	49	136	208	158	71	29	95	91	113	122	135	651
K27	40	90	215	132	36	72		110	86	87	68	83	545
K39	26	95	84	131	14			63	75	48	42	33	324
K44	17	257	195	72				102	113	82	59	65	524
K46	17	196	243	33				119	74	43	59	58	472
K48	60+	40	228	545	342	109	46	222	227	214	184	241	1310
K49	51	49	167	174	206	80	39	148	152	125	81	60	715
K51	17	62	206	106				65	66	66	55	60	374
K53	22	164	167	72				88	60	54	59	54	403
K54	18	202	326	67				160	102	36	71	65	595
B1	60+	71	204	261	139	95	87	137	153	143	139	147	857
B29	28	42	146	217	55			87	60	70	74	81	460
B30	34	42	159	194	125			99	87	83	84	67	520
B31	27	30	173	327	55			83	127	126	99	68	585
B33	51	31	267	436	274	171	70	237	229	209	201	136	1249
B34	34	92	349	661	225			238	198	194	222	236	1327
B36	27	122	305	379	79			153	163	175	120	121	885
B37	26	44	316	331	28			103	123	156	124	109	719
B38	28	92	398	311	43			160	201	114	96	112	844
G19	60+	215	380	303	176	223	261	299	266	204	251	238	1558
G20	56	202	467	517	343	96	43	268	330	276	270	256	1668
W2	60+	218	220	255	194	79	65	210	165	145	127	173	1031
W4	26	69	122	178	11			58	24	54	121	65	380
W5	36	63	112	217	86	13		108	129	88	36	22	491
W6	30	146	237	366	73			104	142	195	162	114	822
W7	25	90	130	105	4			44	45	39	78	78	329
W8	42	243	456	278	218	67		294	192	158	184	139	1262
W9	60+	64	338	494	209	158	125	293	277	198	152	175	1388
W10	60+	71	205	181	88	41	47	99	129	96	83	126	633
O14	60+	78	378	343	158	179	119	209	197	226	235	178	1255
O15	27	1	141	539	55			198	135	107	60	37	736
O17	49	110	223	234	210	47	7	139	136	133	163	121	831
O18	28	357	625	486	47			259	237	335	239	187	1517
O19	29	176	285	253	67			142	159	187	134	116	881

* By "fibrous" roots is meant those roots less than ⅛ inch in diameter.

† Each figure represents the number of fibrous roots in 6 feet length of pit face, at the depth noted. The "totals" are obtained by adding these figures.

‡ Each figure represents the number of fibrous roots from 0 to 5 feet in depth, at the distance from the tree noted. The figures for the 5-foot distance are obtained by averaging the 2 feet of pit face nearest the tree.

"LAMBERT MOTTLE", A TRANSMISSIBLE DISEASE OF SWEET CHERRY[1]

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In 1939, previously unobserved symptoms appeared in four experimental Lambert trees in the laboratory grounds. These symptoms were at first thought to be those of mottle leaf on the Lambert variety. They were later shown to be due to a separate and distinct transmissible disease. The name "Lambert mottle" is suggested because Lambert is the only variety known to show symptoms.

OCCURRENCE

The four experimental Lambert trees in which "Lambert mottle" was first observed had all been used in attempts to transmit mottle leaf to the Lambert variety. This mottle leaf had been originally obtained from a Napoleon (Royal Anne) tree in Nelson City in the Kootenay District. Examination of most of the cherry trees in that city showed considerable mottle leaf in the Bing, Napoleon, and Republican varieties but no "Lambert mottle" in the Lambert variety. Surveys made in the Okanagan Valley between 1938 and 1941 covered over 9,000 cherry trees, nearly all of which were of the sweet varieties, but revealed only 9 trees naturally infected with "Lambert mottle."

SYMPTOMS

Only the Lambert variety is known to show symptoms (Figure 1). The terminal shoots of trees in which the disease is well established appear normal in the early spring, but, as the season advances, all the upper buds on many of them either fail to move, or swell a little and then die. The development of the other leaf buds and of the flower buds is both late and irregular. In the early summer, the foliage appears slightly thin, but individual leaves are normal in appearance and most of them are full size. In early June a slight yellow interveinal mottle begins to appear on the older leaves, and is soon followed by numerous small spots of a purplish or chocolate colour which later becomes more brown. These spots form lines close beside the veins, and also irregular lines and rings or partial rings without relation to the veins. The lines of minute purplish spots are usually surrounded by a poorly defined area of a greenish yellow. In some leaves a similar greenish yellow pattern occurs without any purple spots. In addition to these symptoms, and occurring without apparent relation to them, there are areas of the leaf up to 3 cm. in length which become brown and torn but do not usually separate clearly at the margin. Typically the margins of these areas are irregularly curved but sometimes a sharp point extends along a small vein. The brown areas occur on any part of the leaf blade except the mid-rib. In midsummer the basic normal green of the oldest leaves changes to yellow while the greenish yellow

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pattern becomes slightly more green. Defoliation varies from year to year. It may commence with the oldest leaves in early July and half of the leaves may fall prematurely. The one symptom which can be observed at all times is the form of branching that results from the production of new shoots from part way down the previous season's growth. Diseased trees set only a light crop and sometimes many of the fruits do not reach maturity. In some cases fruits of normal size and colour have abnormally short and curved pedicels. In some trees nearly all of the fruits arise from fruit buds carried either singly on the lower part of the 1-year-old wood or on a few spurs on the upper or outer part of the 2-year-old wood. The small number of growing fruit spurs may be very pronounced. The disease becomes progressively more serious for several years and the death of twigs and larger branches occurs. The death of whole trees has not been observed but there are some indications that young trees may be killed in course of time. In older trees the disease appears to become stabilized.

EXPERIMENTAL WORK

Unless otherwise stated, all experimental trees were young trees growing out-of-doors, and all attempted transmissions were made by grafting tissue from diseased trees onto healthy ones either by shield budding in the summer or by grafting dormant scions in the spring.

"Lambert mottle" has been transmitted to 17 Lambert trees and every attempted transmission has given positive results. The disease has been transmitted to Lambert six times from Bing tissue and eleven times from Lambert tissue. It has been transmitted to Lambert from four sources: a Napoleon source in Nelson containing mottle leaf also, and three Lambert sources in the Okanagan Valley containing "Lambert mottle" only. Attempts to transmit "Lambert mottle" to Bing and Napoleon trees from these four sources and from one other Lambert source in the Okanagan Valley produced no visible effect of "Lambert mottle" in 27 Bing trees and 14 Napoleon trees. Diseased Lambert branches grew in some of these trees for years with no visible effect on the rest of the tree. No attempts have yet been made to demonstrate the presence of the virus in these Bing and Napoleon trees. Normal Bing buds set on a diseased Lambert tree produced branches which grew normally till the Lambert tree was nearly dead. Some of the Bing leaves then showed a few rather bright yellow ring spots. "Lambert mottle" was transmitted to two Lambert trees from buds taken from these Bing branches.

Attempts to transmit mottle leaf, originally obtained from the above-mentioned Napoleon source in Nelson, to two pairs of Lambert trees produced "Lambert mottle" in all of the trees. The first pair of Lambert trees had been started in pots in the greenhouse and had received single- or multiple-bud dormant scions from a Bing tree infected directly from the Napoleon source in Nelson. No symptoms appeared in the greenouse and the trees were soon planted out-of-doors where symptoms of "Lambert mottle" appeared later. From each of this pair of Lambert trees "Lambert mottle" was transmitted to 2 Lambert trees and mottle leaf was transmitted to 4 Bing trees and 2 Napoleon trees, showing that the two viruses were both present in this pair of Lambert trees which showed symptoms of

"Lambert mottle" only. The second pair of Lambert trees had been treated with material from a Bing tree infected with mottle leaf as a result of being splice-grafted to the Bing tree infected directly from the Napoleon source in Nelson. Dr. H. R. McLarty had taken scrapings of the cambium from the diseased tree and inserted these cambium scrapings under the bark of the healthy trees. From this pair of Lambert trees "Lambert mottle" was transmittted to 3 Lambert trees, transmission being obtained

FIGURE 1. Symptoms of "Lambert mottle."

A. Left, diseased shoots showing late and irregular development and death of terminal buds. Right, normal.

B. Pattern on a green leaf.

C. Pattern and brown torn areas on a yellow leaf.

D. A young diseased Lambert tree, September, 1939.

E. The same tree, October, 1944.

from each tree of the pair. No mottle leaf, however, was transmitted to any of the 9 Bing trees and 6 Napoleon trees that received scions or buds from this pair of Lambert trees, showing that this pair of Lambert trees contained the "Lambert mottle" virus but did not contain the mottle leaf virus. Thus in this experiment "Lambert mottle" and mottle leaf were both transmitted by budding and grafting, but only "Lambert mottle" was transmitted by cambium scrapings inserted under the bark, although in a different experiment mottle leaf had been transmitted by cambium scrapings. Mottle leaf produces pronounced sumptoms on Bing and Napoleon trees but has little or no effect on Lambert trees. "Lambert mottle" produces marked symptoms on Lambert trees but no definite symptoms have so far been observed on Bing or Napoleon trees. In Bing trees, from which "Lambert mottle" was transmitted to Lambert trees, the symptoms were indistinguishable from those of mottle leaf alone. Lambert trees, carrying both diseases, showed only "Lambert mottle" and the presence of the other disease had no visible effect.

Leaf symptoms of "Lambert mottle" appeared in the first year after budding. Symptoms on the twigs began to appear in some trees in the second year. Later the disease became progressively more serious in some trees while in others it appeared to become stabilised.

SUMMARY

1. A new transmissible disease of sweet cherry is described.

2. The disease is only known to produce symptoms on the Lambert variety.

3. It has occurred naturally, both alone and together with mottle leaf, but it is rare.

4. Transmission to Lambert trees has been obtained without fail.

5. Pronounced symptoms are produced by "Lambert mottle" on Lambert trees and by mottle leaf on Bing and Napoleon trees, but there is little or no visible effect of "Lambert mottle" on Bing or Napoleon trees, or of mottle leaf on Lambert trees. When both diseases are present in a tree the symptoms depend on the variety of the tree and only one disease is visible, the other having no apparent effect.

SOLONETZ SOILS IN ALBERTA

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Solonetz is a term first used in the Russian literature for a soil that is believed to have developed from a structureless, often salt encrusted, saline soil. Under favourable conditions this development has resulted in a soil that has a very tight subsoil with a distinct and characteristic structure. While the mechanism of, and the conditions necessary for this development is not as yet clearly understood, the resultant structure is strikingly different from that of other soils. Soils having this unfavourable structure are known to occur in scattered patches and occasionally as large unbroken areas throughout the more arid sections of the world. They are of fairly common occurrence in the Great Plains area of the United States, and in Western Canada. Large areas have been outlined in Alberta (see map, Figure 1) and further soil surveys will no doubt extend the present reported acreage considerably.

Prior to the use of the term solonetz, such soils were called by a variety of local names the most common of which were "blow-out," "burn-out," "buffalo-wallow," "slick-spot" or "gumbo-spot" soils. Areas of such soils are frequently characterized by a patchy, pitted surface (Figure 2) which has given rise to the variety of local terms in common use. Such soils are droughty, difficult to break up, difficult to handle and generally inferior agricultural soils. This inferiority seems to be due largely to the unfavourable characteristics of the subsoil and is most marked when this subsoil is encountered within plow depth.

Typical solonetz profiles in Alberta have the following characteristics:

Horizon A

A rather porous soil that is often slightly granular. It can readily be broken up into small irregular lumps or clods that have considerable fine powdery material. The colour of this horizon may vary from a brown to a black depending on the soil zone. Frequently it is somewhat grayer than the A horizon of typical zonal soils. It varies in thickness from 2 inches to 24 inches, although most frequently it is from 4 inches to 10 inches thick. It tends to be shallower in the brown and dark brown soil zones than in the black and gray. While its texture is most frequently a loam or a silty loam, it does vary from a loamy sand to a clay. Frequently the lower part of this horizon is characterized by a gray, finely laminated or foliated structure. This platy A_2 subhorizon may vary from merely a thin layer to a thickness of a few inches.

Horizon B

The characteristics of this horizon form the principal and most distinctive feature of the solonetz. Usually three subhorizons can be distinguished as follows:

Sub-Horizon B_1. A very compact horizon that becomes sticky and water tight when wet and very hard when dry. On drying it breaks into

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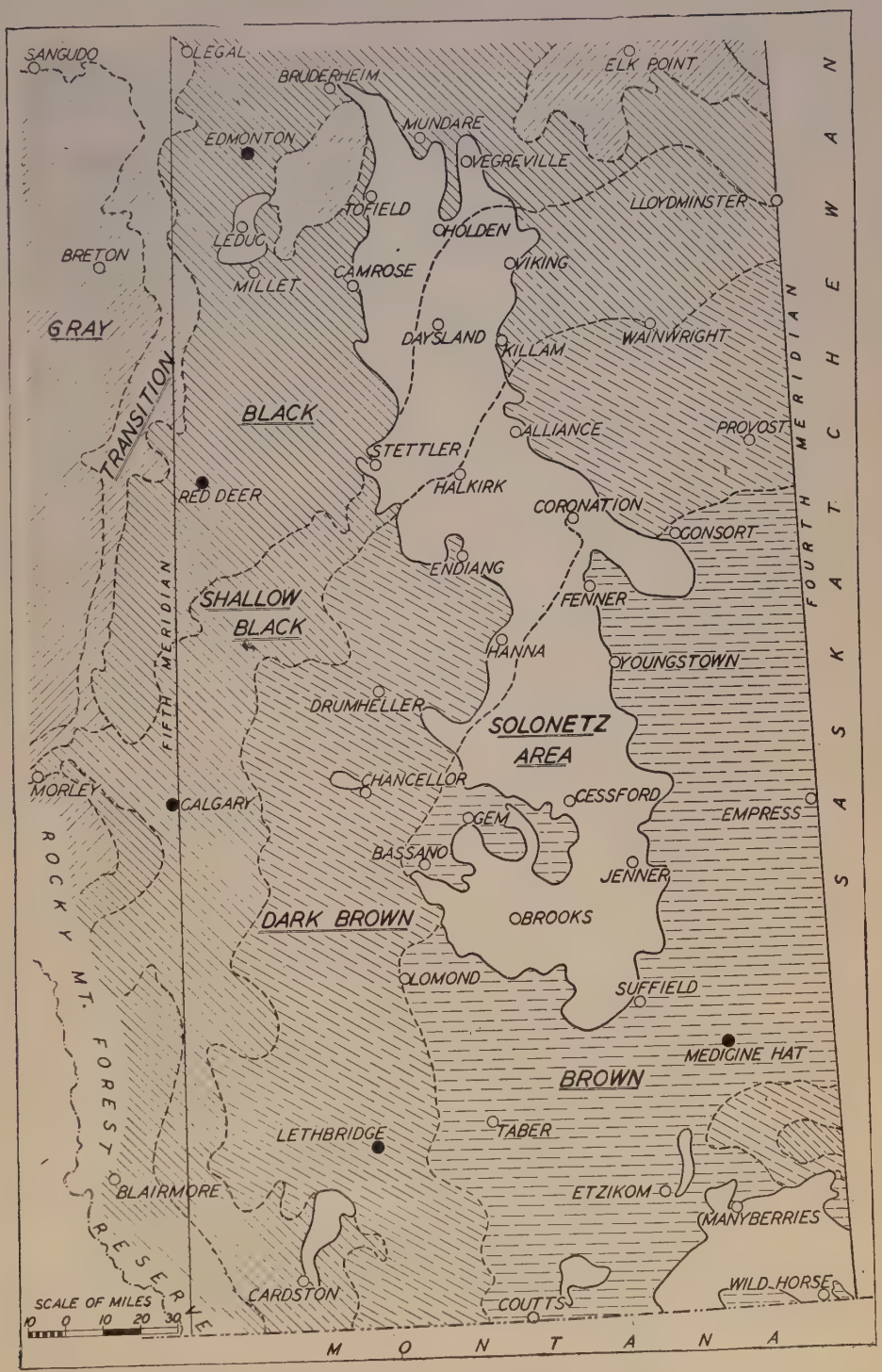

FIGURE 1. Map of a Portion of Alberta Showing Soil Zones and Solonetz Areas.

coarse angular columns often characterized by a well rounded cauliflower-like top (Figure 8). For a depth of about $\frac{1}{8}$ inch these columns are often capped with a grayish, very hard, dense layer. The columns are usually about 1 to 2 inches wide and rarely more than 8 inches long. They are made up of very hard small angular clods which are often coated with a dark shiny film that gives them a somewhat waxey or glazed appearance.

Sub-Horizon B_2. Here the vertical cracks that separate the columns become more irregular and break the soil mass into rough irregular cubes. The glazed appearance of the small clods is less marked and is frequently absent in the lower part of this sub-horizon. The material is not as compact or as impermeable as that in the B_1.

Sub-Horizon B_3. This has usually much the same structure as the B_2 but contains lime and very frequently considerable quantities of gypsum within a short distance below the top of the lime layer. It is usually lighter in colour, often mottled, and is much more permeable than the B_2 sub-horizon.

The depth to and thickness of these sub-horizons vary with the location, the soil zone, and with the nature of the underlying parent material. The B_1 varies from 3 to 8 inches in depth, the B_2 from 6 to 24 inches and the B_3 is encountered at depths varying from 12 to 36 inches below the surface.

The B_1 is the darkest coloured of these and it may be a greasy black, dark grown, drab gray or olive gray. Below the B_1 the colour gets lighter and grades without any sharp changes into that of the parent material. In the brown and dark brown soil zones the colour of the B_1 is frequently darker than that of any other horizon in the profile.

The contact between the A and B horizons is characteristically very abrupt and clear-cut, totally unlike that of other soils. In the latter there is a very irregular and often indistinct break between these horizons.

Usually the texture of the B horizon is a clay or clay loam. The B_1 sub-horizon is the heaviest and frequently has an accumulation of the very fine clay particles.

Horizon C

This horizon varies in different regions as regards its depth and texture, and its characteristics depend on the derivation of the parent material. In some cases it may be found within 18 inches of the surface but more frequently it is found at depths greater than 24 inches below the surface. It may consist of water or wind laid deposits, glacial till, or in many cases of the somewhat mixed or sorted products of the underlying bedrock. In the latter case its depth is usually quite shallow and the bedrock is relatively close to the bottom of the B_3 horizon.

In the samples studied to date the pH of the A horizon varies from mildly alkaline in the brown soil zone to mildly acid in the black soil zone. Alkalinity increeases with depth; the B_1 horizons average about pH 7.6, the B_2 about pH 8, and the B_3 and C about pH 8.2. Comparable non-solonetz soils have about the same or slightly less acid A horizons, generally somewhat less alkaline B_1 horizons and about the same alkalinity in their remaining horizons.

FIGURE 2. Typical Solonetz topography in the brown and dark brown soil zones. Note the pitted nature and in the foreground the depth of A horizon overlying the frequently exposed B horizon.

FIGURE 3. Eroded cut showing very close proximity of underlying bedrock. This is typical of much of the flat solonetz area in the neighbourhood of Cessford, Coronation, Halkirk and Holden.

FIGURE 4. Solonetz topography in the Black and Shallow Black Soil Zones. Flooded patches such as shown are typical during and sometimes after rainy spells. Such soils absorb water very slowly.

The horizons described are, in most cases, true genetic horizons, and as such one might expect them to reflect a definite chemistry of soil formation. However, there is as yet considerable difference of opinion regarding this point.

Kellog (3) in discussing these soils says in effect: "The solonetz represents one stage in a cycle of one group of saline soils. The group required is the alkaline group or that in which sodium salts predominate. If the group had a predominance of calcium salts rather than sodium no solonetz would be formed." The solonetz soils studied to date in Alberta, and reported by MacGregor and Wyatt (4), have had calcium predominant in the base exchange. As these authors point out, similar studies elsewhere on this continent have shown that with but one exception, calcium and magnesium are predominant rather than sodium. As a result, some pedologists have been hesitant to use the name solonetz. However, considering the widely divergent views, it seems obvious that until such time as more convincing proof is available these soils cannot be strictly defined in chemical terms, especially in regard to the nature of their base exchange complex. They can easily be recognized by their structure and it is mainly this structure that sets them apart from other soils. Furthermore it is doubtful if solonetz soils always represent but one stage in a cycle of one group of saline soils. Our observations lead us to agree with Nikiforoff's (6) suggestion that very often the solonetz and the other saline members "may be genetically independent soil formations whose development and distribution is controlled by different factors."

Although considerable of Alberta's solonetz soils occur as occasional patches of varying size intermixed and forming complexes with other soils, their most striking occurrence is in the belt (see map, Figure 1) that extends from Bruderheim to near Suffield, a distance of about 250 miles. This belt averages about 35 miles in width and attains its maximum width of approximately 60 miles in the vicinities of Brooks and Coronation. Patches of solonetz of varying size and not as yet outlined occur north of this belt and a fairly large area occurs south of this belt lying between Manyberries and Wild Horse in the south east part of the province. This latter area has much the same characteristics as the southern portion of the main belt and it may have been, at one time, a part of that belt. However, it is separated now by an area in which the prevailing conditions seem to be generally unfavourable to the development of solonetz. Outside of these, many small areas have been mapped and the largest, occurring near Etzikom, Coutts, Cardston, Chancellor and Leduc, have been outlined on the accompanying map. Solonetz areas are also known to occur in the neighbourhood of Breton, Legal, and between Red Deer and Millet, but their boundaries have not yet been determined. Similarly in the area north of that shown on the map solonetz patches of undetermined size are known to occur at or near Gibbons, Busby, Clyde, Grande Prairie, Fairview and Grimshaw.

As indicated on the map the solonetz area extends through the brown, dark brown, shallow black and black soil zones of the province. Solonetz soils are also known to occur in the transition and gray soil zones. In addition they are found under a wide range of soil textures. However,

FIGURE 5. Solonetz profile typical of much of the flat solonetz area in the black and shallow black zone. In old road cuts, such as this, the columnar structure of the upper part of the B horizon is obscured due to the effects of weather.

FIGURE 6. A deeper phase fine sandy loam solonetz profile. In the brown and dark brown soil zones the occurrence of this tight horizon at depths of about 24 inches often improves the agricultural value of such light sandy areas.

while they seem to occur over a wide range of parent materials their best development has been found in areas closely underlain by brackish marine shales and sandstones.

The main belt of solonetz soils is found in a trough that lies between the Viking and Buffalo Lake moraines (8). The area within this trough is level to undulating and is covered over, for the most part, by a shallow mantle of glacial till. This shallow mantle lies either directly on the bedrock (Figure 3), or is sometimes separated from it by other unconsolidated deposits that are chiefly alluvial. The bedrock in this area consists of the Bearpaw formation, the lower members of the Edmonton formation and the upper members of the Belly River formation as outlined and described by Allan (1). These formations are bentonitic and contain varying amounts of soluble salts. The salty impermeable nature of these beds and the relatively thin covering of glacial till may have furnished conditions favourable to the development of this large solonetz belt.

The areas as outlined on the map represent approximately 7 million acres or 20% of the area lying south and east of Edmonton and east of the fifth meridian. In these areas solonetz soils are either continuous or form not less than 20% of a mixture, and those in which the B horizon occurs at depths less than 12 inches below the surface. Outside of the solonetz areas shown on the map there are in addition at least 3 million acres of soils in which the B horizon occurs at depths greater than 12 inches below the surface. In light, sandy soils the presence of the tight horizon at depths greater than 12 inches (Figures 6 and 7) seems to improve their value as arable soils because of its water retention.

The large amount of abandonment that has occurred in the outlined areas is evidence of the fact that these soils are inferior agricultural soils. Their inferiority becomes more pronounced in dry years or prolonged periods of drought. Regardless of the conditions that may have been necessary for their formation, they are not now alkaline soils. Neither are they any more deficient in total plant food than other neighboring soils. Their inferiority seems to be due to the unfavourable physical condition of the B horizon—particularly the B_1 sub-horizon—which tends to restrict the feeding range of plants. In this connection Hide (2), studying the causes of certain unproductive spots in the black soils of the Red River Valley, concluded that these spots will not appear when the subsoil has been well supplied with moisture by means of a preceding season of clean fallow, by exceptionally favourable rains or by irrigation.

While it is desirable that there should be an adequate supply of moisture it is at least equally desirable that this supply be available to the plant roots. In his review of the literature regarding the "Plant Growth Relations on Saline and Alkali Soils" Magistad (5) points out that in such soils there is a decrease in available water due to the high osmotic pressure of the soil solution. Direct measurements have shown that water absorption by plants is reduced as the osmotic pressure of the subsoil is increased. He adds that some of these soils take on unfavourable physical properties in that they become dispersed, do not drain well, and will not readily "take" water with the result that plants grown on them may suffer from an actual lack of water, a lack of oxygen in the soil air, a lack of

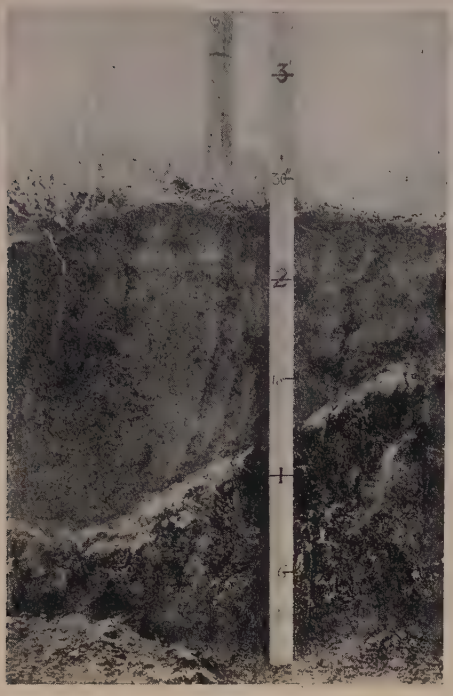

FIGURE 7. A sandy loam solonetz profile in the dark brown soil zone. Note the variable depth of the A horizon. In heavier textured solonetz soils the surface is usually much shallower.

FIGURE 8. A portion of the B horizon of a typical solonetz profile. Note the cauliflower like appearance of the top of the B_1 sub-horizon and the columnar structure of the upper 4 inches. These "round tops" are capped by a very hard, dense layer. The portion on the left side nearest the rule is a side view, while that on the right is a top view.

available nutrients and many other nutritional disorders. It would seem very desirable therefore to adopt some means of culture that would lead towards breaking and loosening up this horizon and then keeping it loose to promote an adequate movement of both air and water and enable plant roots to more easily penetrate this horizon. Experimental work (7) conducted on solonetz soils in the dark brown zone of Saskatchewan has shown that some improvement in tilth can be obtained by raising sweet clover, applying farm manure, occasional deep plowing, frequent summerfallowing, and a thorough preparation of the seedbed.

In the brown soil zone of Alberta past experience indicates that it is very difficult to adopt a satisfactory economical means of opening up this compact subsoil typical of solonetz. The low average annual precipitation of 12 inches makes the growing of such deep rooted soil improving crops as alfalfa and sweet clover very uncertain. Crested wheat grass while not as desirable a soil improving crop, is better adapted to this zone and if seeded down and left for several years it might improve the tilth of these areas. At any rate it would improve the pasture in areas where the present stand in many places is quite poor. At the present time much of the non-irrigated solonetz area in this zone is poor arable land and where once farmed is now mostly abandoned. The problem is a serious one since solonetz soils occupy about one-third of the area of the brown soil zone.

In the dark brown, shallow black, black, transition and gray soil zones these areas although difficult to work and uncertain of success might be improved with less difficulty. The average annual precipitation of from 15 to 20 inches is much more favourable and in seasons of good moisture many of the solonetz areas in these zones have produced good crops. With deep plowing and the establishment of alfalfa in the moister sections, and sweet clover in the drier sections, some hope of permanent improvement might be expected. However, it must be borne in mind that this process of improvement is a continuous one and the growing of soil improving crops and occasional deep plowing must be recognized as permanent features of the crop rotation. In these areas of more favourable moisture the solonetz are not so badly pitted and the depth to the B horizon is somewhat greater than is the case in the brown soil zone. Nevertheless solonetz soils must still be considered as definitely inferior soils. Successful reclamation seems to depend largely on the depth to the B_1 horizon, and on the depth to and the nature of the underlying parent material. In these zones abandonment has largely occurred in those solonetz areas in which bedrock occurs within a few feet of the surface (Figures 3, 4, and 5).

Much of the southern part of Alberta is receiving favourable consideration for future irrigation schemes. In some cases portions of the areas under consideration consist of solonetz soils. Under irrigation, there is no doubt that some of these soils will prove very satisfactory. The outstanding example of the successful reclamation of solonetz soils through irrigation is to be found in the vicinity of Brooks. With the judicious use of water, accompanied by the raising of deep rooted soil-improving crops, the compact layer of the solonetz has been broken up sufficiently to permit of good growth (Figure 9). However, in this area the underlying C horizon

FIGURE 9. A profile typical of the medium textured irrigated soils of the Brooks area. The area has been levelled over, and while there is still a distinct and sharp break between the A and B horizons, the latter has lost much of its compact characteristics through irrigation and the growing of deep rooted crops.

consists of stratified sedimentary deposits of considerable depth that are quite permeable and permit ready percolation, once the heavy compact layer has been penetrated. It is unwise to assume on the basis of the success in the Brooks area, that all solonetz soils are amenable to irrigation. Those that do not have such a favourable subsoil or a desirable slope may on irrigation become waterlogged and saline.

SUMMARY

Solonetz soils have a very tight subsoil with a distinct and characteristic structure. Such soil areas are characterized by a patchy pitted surface that has given rise to the variety of local names used for them. They are of frequent occurrence in Alberta, and only the shallower of the continuous variety or of the mixed type in which solonetz soil represents not less than 20% of the mixture have been outlined in the solonetz areas. These areas represent a total of about 7 million acres in that part of Alberta lying south and east of Edmonton, and east of the fifth meridian. Their most extensive development has been found in areas closely underlain by brackish marine shales and sandstones, and their most striking occurrence is in the trough lying between the Viking and Buffalo Lake moraines.

Solonetz soils are inferior agricultural soils, and their inferiority seems to be due to the unfavourable condition of the B horizon. Improvement in tilth can be expected only if some means of culture is adopted that will

lead towards breaking and loosening up this horizon and then keeping it loose. In the brown soil zone of Alberta past experience has shown that it is very difficult to adopt an economical practice that will improve the soil. In the other zones, where moisture is not such a limiting factor, the growing of such deep rooted soil-improving crops as alfalfa and sweet clover may bring lasting improvement if such crops are included as permanent features of the crop rotation. The success of irrigation on solonetz soils seems to depend largely on the nature and depth of the material underlying the B horizon.

ACKNOWLEDGEMENT

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DÉTERMINATION DU MAGNÉSIUM ÉCHANGEABLE DANS LES SOLS PAR LA 8-HYDROXYQUINOLÉINE[1]

MICHEL A. PINEAU[2] ET LUCIEN CHOINIÈRE[3]

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D'après plusieurs auteurs (1, 6), la détermination de faibles quantités de magnésium, sous forme de pyrophosphate, donne des résultats erronnés, le plus souvent trop élevés.

La précipitation du magnésium, sous forme de quinoléate de magnésium, par une solution alcoolique à 5% de 8-hydroxyquinoléine, donne des résultats beaucoup plus satisfaisants.

HISTORIQUE

Depuis une vingtaine d'années, les travaux sur le réactif 8-hydroxyquinoléine se sont multipliés. D'après Hoffman (3), le principe de la précipitation du magnésium par ce réactif fut utilisé par Hahn et adopté par R. Berg, en 1927, par C. BomsKov, en 1931, et par D. M. Greeberg et M. A. Mackay, en 1932. En 1934, Javillier et Lavollay (5) présentent un travail sur l'emploi de la 8-hydroxyquinoléine pour la détermination du magnésium. Plus près de nous, en 1938-39, Fr. Hormidas et Délorme (4) présentent à l'Office des Recherches Scientifiques de la province de Québec, le résultat de leurs recherches sur le calcium et le magnésium chez les végétaux.

D'après tous ces auteurs et beaucoup d'autres, la précipitation du magnésium sous forme de quinoléate, s'opère en milieu ammoniacal, en présence de chlorure d'ammonium. La présence de l'acide phosphorique et du magnésium du sol, peut fort bien, en milieu ammoniacal, donner naissance à un phosphate ammoniaco-magnésien. Travailler dans un tel milieu peut occasionner des pertes de magnésium. Le fait a été constaté par Fr. Hormidas et Délorme (4). Aussi, certains auteurs éliminent-ils les phosphates avant la précipitation du magnésium.

Dans le présent travail nous contournons la difficulté en précipitant le magnésium, sous forme de quinoléate, en milieu sodique en présence de tartrate de sodium.

Comparaison de la méthode proposée avec la méthode au pyrophosphate.

Nous avons déterminé le Mg total sur quatre échantillons de sol. Après avoir fait les fusions en double selon la méthode officielle de l'A.O.A.C., on élimina la silice et ramena à un volume connu. Deux aliquotes de chaque sol servirent à la détermination du Mg en utilisant la méthode proposée. Les autres aliquotes, placées dans des fioles scellées, furent analysées selon la méthode officielle de l'A.O.A.C., cinquième edition, 1940. Voici les resultats obtenus (Tableau 1):

TABLEAU 1

Echantillon	Méthode proposée	Méthode au pyrophosphate
16503	2.05% MgO	2.20% MgO
16504	0.84% MgO	0.86% MgO
16505	1.14% MgO	1.34% MgO
16506	1.32% MgO	1.32% MgO

[1] Résumé d'une thèse de maitrise présentée en 1942 à la Faculté d'Agriculture de l'Université Laval.

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La méthode au pyrophosphate a donné des résultats légèrement supérieurs.

Comparaison de la méthode proposée avec les autres méthodes à la 8-hydroxyquinoléine, opérant en milieu ammoniacal et en présence du chlorure d'ammonium.

Neuf portions de 25 gr. du même sol furent lavées chacune avec 1000 cc. d'acide acétique, N/2, selon la méthode décrite par Williams (7). Les neuf litres de la solution furent partagés en 18 aliquotes de 500 cc. chacune, correspondant à 12.5 gr. de sol.

Dans la méthode proposée et décrite plus loin l'acide phosphorique et le Mn ne sont pas éliminés avant la précipitation du Mg. En étudiant le Tableau 2, nous constatons:

(a) Que l'acide phosphorique du sol, en présence du Mg. et de NH^4OH, peut former un phosphate ammoniaco-magnésien, et par conséquent donner des résultats trop faibles;

(b) Que le Mg ajouté fut presque entièrement trouvé avec la méthode proposée.

Tableau 2

——	N°	Méthode proposée	N°	Autres méthodes
Dans 12.5 gr. sol	1	10.00 mgrs. de Mg.	10	9.76 mgrs. de Mg.
	2	10.17 mgrs. de Mg.	11	9.73 mgrs. de Mg.
	3	10.07 mgrs. de Mg.	12	9.44 mgrs. de Mg.
12.5 gr. sol + 1.00 mgr. de Mg.	4	10.95 mgrs. de Mg.	—	*
	5	10.95 mgrs. de Mg.	14	10.89 mgrs. de Mg.
	6	11.11 mgrs. de Mg.	15	10.94 mgrs. de Mg.
12.5 gr. sol + 2.00 mgr. de Mg.	7	12.00 mgrs. de Mg.	16	11.65 mgrs. de Mg.
	8	12.00 mgrs. de Mg.	17	11.84 mgrs. de Mg.
	9	12.02 mgrs. de Mg.	18	11.75 mgrs. de Mg.

* Perdu.

Il est à remarquer, en plus, que le Mn fut déterminé dans les précipités et les filtrats. Avec la méthode proposée, nous avons trouvé que le Mn ne précipite qu'à l'état de trace. Le reste se trouve dans le filtrat. En opérant en milieu ammoniacal, le Mn précipite totalement.

Description de la méthode proposée.

25 gr. de sol, séché à l'air, sont lavés avec 1000 cc. d'acide acétique N/2, selon la méthode de Williams (7). Le filtrat est évaporé à sec, calciné à 500° C. durant environ 30 minutes. Après la détermination des bases totales échangeables, on élimine le Fe et l'Al en les précipitant sous forme d'hydroxydes par NH^4OH (1 : 1), en présence de NH^4Cl et de méthyl rouge comme indicateur. Au filtrat légèrement acidifié par HCl dilué et porté à l'ébullition on ajoute un excès d'oxalate d'ammonium, puis quelques gouttes de bromo-phénol bleu; la solution se colore en jaune.

On ajoute goutte à goutte NH^4OH (1 : 1) jusqu'au virage violet très net, ce qui correspond à un pH de 4.2 à 4.6. On laisse refroidir et on filtre, en lavant à l'eau très chaude. En opérant dans ces conditions, il ne précipite pas de Mg et aucun sel alcalin n'est entraîné (2).

Le filtrat contenant le Mg est évaporé à sec. On ajoute 25 cc. de HNO^3 concentré, on laisse digérer pendant 12 heures, en recouvrant le bécher d'un verre de montre. On évapore à sec, calcine au four à 400° C. pour volatiliser les dernières traces d'ammoniaque.

Le résidu est dissous dans HCl dilué, traité par 75 cc. d'eau et 3 gr. de tartrate de Na, chauffé jusqu'au point d'ébullition, en agitant pour dissoudre le tartrate de Na. On neutralise par NaOH, 2N, en présence de méthyl rouge. On ajoute alors 5 cc. d'une solution alcoolique de 8-hydroxyquinoléine, et, immédiatement, 15 cc. de NaOH, 2N. On recouvre le bécher d'un verre de montre et on le place sur un bain-marie à l'ébullition durant 45 minutes environ. On laisse alors refroidir et reposer durant 2 à 4 heures. On filtre dans des creusets de Gooch ou de verre Iéna. Le précipité est lavé à l'eau froide très légèrement ammoniacale (1 : 50), séché à l'étuve à 160° C., pendant au moins 2 heures, refroidi et pesé. Le quinoléate de Mg obtenu contient 7.78% de Mg.

RÉSUMÉ

En présence de tartrate de Na et de NaOH, la précipitation du Mg peut s'effectuer quantitativement par la 8-hydroxyquinoléine, en présence de l'acide phosphorique et du manganèse déplacés en lavant le sol par l'acide acétique N/2, ou tout autre acide dilué ou sel neutre employés pour le déplacement des bases échangeables du sol. Dans un tel milieu l'acide phosphorique n'a aucune influence sur la précipitation du Mg. Le Mn ne précipite qu'à l'état de trace, même pour des quantités relativement considérables.

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RÉSUMÉ

Magnesium is precipitated quantitatively by 8-hydroxiquinoline in presence of sodium tartrate and sodium hydroxide. The presence of phosphoric acid and manganese that can be drained by washing the soil with acetic acid N/2, or any other diluted acid, or neutral salt which has been used to extract the exchangeable bases, does not affect the former precipitation. Only minute amounts of manganese can be detected in the precipitate even when a large quantity is present.

METHYL BROMIDE FUMIGATION OF PLANT PRODUCTS IN RAILROAD FREIGHT CARS WITH SPECIAL REFERENCE TO WORK SUPERVISED BY THE DOMINION DEPARTMENT OF AGRICULTURE DURING 1944[1]

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As a result of the finding of severe insect infestations in cargoes of plant products imported into Canada in the early part of the present war, the Division of Plant Protection, Dominion Department of Agriculture, was obliged in 1942 to institute a policy of inspecting such cargoes immediately on arrival in this country and insisting on treatment when considered necessary. A more detailed account of this situation, with the considerations of policy involved, was given by McLaine (4) in a review of the war activities of the Divisions of Entomology and Plant Protection since 1939. In brief, the object of this work is not merely to disinfest the imported goods themselves, but also to prevent the spread of the large insect populations involved to other commodities, during handling in steamship sheds, railroad cars, lake and canal steamers, trucks and terminal warehouses.

During the season of 1944 large bulk consignments of plant products arrived in this country in steamships. These importations were made exclusively by one agency, the Bulk Purchasing Division of the Commodity Prices Stabilization Corporation, which operated under the Canadian Wartime Prices and Trade Board. The active co-operation of the officials of this organization enabled a considerable amount of preliminary arrangement to be made prior to the arrival of each shipment.

The activities of this Division in inspecting shipments and stipulating treatments had the effect of bringing the value of this type of control to the attention of representatives of food distributing organizations and transportation companies. As a result, our inspectors were asked to supervise the treatment of export shipments of foodstuffs, notably consignments sent by the International Red Cross to distressed European countries. Strictly speaking, this activity lay outside the scope of duties originally envisaged for this organization, but the work was gladly undertaken to ensure that all food reaching such countries should be as free as possible from insects liable to cause deterioration.

All the treatments were carried out by qualified pest control operators or concerns expert in industrial fumigation, working under the supervision of our inspectors.

The majority of the treatments were made in railroad cars, and the fumigant used was exclusively methyl bromide. This paper, therefore, deals with a discussion of the railroad car fumigations and the use of methyl bromide as a fumigant in this technique.

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GENERAL ORGANIZATION

With the exception of two cargoes which arrived at New York, all the import shipments were unloaded at Canadian ports. The latter were inspected immediately on docking by officers of this Division, and arrangements were also made for one of our inspectors to examine on the dock a cargo of peanuts unloaded at New York. One lot of cotton seed meal shipped through New York, reached the ultimate consignees at different points in Canada before severe infestation by the cigarette beetle, *Lasioderma serricorne*, F. was detected.

For the most part the district inspectors were advised well in advance of the arrival of the steamers and, acting on the assumption that such commodities as peanuts would be infested, as they invariably were, made plans for their handling and treatment. The arrangements consisted, for the most part, in ensuring that the railroad company had an adequate number of suitable steel box cars on hand and in seeing that well qualified fumigators were available with supplies of the fumigant.

If the consignment was found to be so infested that treatment would be required, the importer was informed immediately, as among other considerations, the work would be done at his expense. The importer and the transportation company responsible for moving the goods inland having already decided if the treatments were to be made at the port of arrival or at final destination, arrangements were completed with the fumigators concerned. During 1944, both methods were tried, i.e. by fumigating the railroad cars containing the goods before they left the seaport or by delaying treatment until the cars arrived at or near destination. As far as this division was concerned, it was greatly preferable for the work to be done at the port of arrival. In actual practice, too, this was found by the railway companies to be the most convenient method and will probably be followed more closely in the future.

For the most part the cars employed were of 3,710 cubic feet capacity and were usually loaded with 400 to 500 bags of commodities such as peanuts or chick peas, a total commodity weight of approximately 70,000 to 90,000 pounds.

The loaded railroad cars were diverted, as far as possible, to isolated yards remote from human habitation where four or more tracks were available for holding the cars during treatment and aeration. It was found desirable to segregate the cars undergoing aeration on a special "ventilation" track, so that the fumigating crews preparing the next batch of cars for treatment would not be exposed to the gases diffusing from those being aired out.

In theory, the inspectors left the carrying out of the treatments to the fumigators, the acceptance of each individual treatment being based on the examination of the cars after aeration. In practice, however, the experience of the inspectors was drawn upon, when required, to advise the fumigators on methods. After completion of the inspection, those cars found to be satisfactorily treated were released for dispatch to destination, while in the small percentage of cases of failure, repetition of the treatment was required. In some cases this involved a more careful sealing of the car or transfer of the goods to a more satisfactory car.

COMMODITIES TREATED AND INSECTS INFESTING THEM

The commodities treated, both for import and export, are summarized in Table 1. A short description of the various commodities, with the insects infesting them, is also given herewith.

Imports

Broom corn: Importations of broom corn from countries other than the United States of America are subject to a quarantine treatment under the provisions of the Destructive Insect and Pest Act irrespective of the finding of infestation or not. This work is usually done by vacuum fumigation at Montreal. In February, 1944, however, an exceptionally large consignment of 6,127 bales was imported in bulk from the Argentine for general distribution in this country. In view of the large size of this shipment, which would take 3 or 4 months to pass through the vacuum vault, and the fact that the large amount of extra handling involved in stopping the goods at Montreal was to be avoided under wartime conditions, a special experimental project was undertaken whereby a method was worked out for treating the broom corn at temperatures between 30 and 40 degrees F. in steel box cars at the point of unloading. This is being made the subject of a separate report.

TABLE 1.—SUMMARY OF BOX CAR FUMIGATIONS SUPERVISED DURING 1944

Name of port or district where treatment carried out	Imports			Exports			Totals	
	Commodity	Weight in short tons	No. of cars	Commodity	Weight in short tons	No. of cars	Weight in short tons	No. of cars
Halifax, N.S.	Cotton seed meal	60	2	Chicory root	45	2	105	4
Saint John, N.B.	Broom corn	1,063	94	Mexican chick peas	2,106	63		
	Indian peanuts	180	5	Wheat	3,282	81		
	Indian peanuts	3,498	97				10,129	340
Quebec, P.Q.	Nigerian peanuts	112	7					
	Cotton seed meal	40	1				152	8
Montreal, P.Q.	Nigerian peanuts	3,948	95					
	Indian peanuts	4,150	94					
	Nigerian peanuts	1,134	27				9,232	216
Toronto, Ont.	Nigerian peanuts	1,455	67					
	Indian peanuts	4,309	105					
	Cotton seed meal	172	3				5,936	175
London, Ont.	Nigerian peanuts	907	33				907	33
Vancouver, B.C.	Indian peanuts	4,341	97				4,341	97
		25,369	727		5,433	146	30,802	873

Peanuts: Large consignments of British Indian and Nigerian shelled peanuts arrived in seven steamers during 1944. These were all found to be severely infested at the time of unloading with the following species of insects:

COLEOPTERA *Tribolium castaneum* Hbst., Red flour beetle
Dermestes ater De G. = *cadaverinus* Fab.
Tenebroides mauritanicus Linn., the Cadelle
Necrobia rufipes De G., Red legged ham beetle
Oryzaephilus surinamensis L., saw-toothed grain beetle

LEPIDOPTERA *Ephestia sericarium* Scott = *kuehniella* Zell., Mediterranean flour moth

Corcyra cephalonica Staint. The rice moth

Plodia interpunctella Hbn., Indian meal moth (in shipment of Indian peanuts at Vancouver only)

Cotton Seed Meal: A shipment of approximately 1,000 tons of cotton seed meal in bags was made from Brazil to Canada in the late spring of 1944. This shipment came direct by rail via an United States port and was transported to a number of consignees throughout Eastern Canada. Several consignees refused to accept this material into their warehouses on finding a large number of insects, subsequently identified chiefly as larvae of the cigarette beetle *Lasioderma serricorne* F., with a few adults of *Tribolium castaneum* Hbn. present also. The matter was brought to the attention of our District Inspectors and it was decided that all the material not as yet consumed should be treated to prevent the spread of the infestation. Several warehouse fumigations with methyl bromide were made on material all ready unloaded on the premises of the consignees, with good results. A number of railroad car fumigations were also successfully carried out.

Exports

Chick Peas: In late April, 1944 at Saint John, N.B., portions of a large shipment of chick peas ("Garbanzos", the seeds of *Cicer arietinum*), en route to Greece through the agency of the International Red Cross, were found by our inspectors to be infested by the cow pea weevil *Callosobruchus maculatus* Fab. (*Mylabris quadrimaculatus* Fab.). These peas had been grown in Mexico and were a gift of the United States Government to the people of Greece. As mentioned before, this Division had no direct jurisdiction over this material, but, in view of the nature and destination of the consignment, gladly co-operated by loaning the services and technical experience of the Saint John staff for the supervision of the fumigation of those carloads of peas found to be infested as they arrived at Saint John. In treating this shipment a considerable amount of reloading had to be carried on in order to transfer the bags to Canadian steel box cars from the original cars, which belonged to United States railroads and were largely of wood construction or were otherwise unsuitable for fumigation.

Wheat: In September, 1944 a shipment of wheat grown in the United States and en route to the British authorities in France via Saint John, N.B., was refused for loading on board the steamer by the steamship agents, following the finding of an outbreak of *Plodia interpunctella* in parts of the consignment, which was packed in 100-pound bags. Our inspectors were again asked to supervise the fumigation work. In this case, also, a considerable amount of reloading of cars had to be undertaken.

Chicory Root: A shipment of 1,046 bags of chicory root on the way from Montreal to Iceland in November, 1944 was found, at the time of loading at Halifax, to be infested with *Plodia interpunctella* Hbn. This material was fumigated in two steel box cars, the interesting aspect of this work being the low temperature at which the treatment was carried out and which will be fully described under "Results."

STEEL BOX CAR CONSTRUCTION AS EFFECTING FUMIGATION WORK

The use of methyl bromide in Canada for fumigating goods in steel box cars was first discussed by Monro and Delisle (5). As was to be expected, it was subsequently found that the success of the treatments depended greatly on the construction of the individual cars, especially in the structure and method of attachment of the roofs. As a result of observations made on the construction of steel box cars during a large number of fumigations, and following consultation with the officials of the mechanical departments of the two principal Canadian railway companies, it has been possible to prepare lists by number series of preferred classes of steel box cars most suitable for fumigation work, in view of their being sufficiently air tight not to require sealing other than at the doors. As a matter of general policy wooden box cars are not permitted to be used, although in exceptional cases, these have been successfully employed. (During the severe steel shortage a few plywood box cars of design similar to recent steel box cars were constructed by the Canadian Pacific Railway Company, as illustrated in Figure 1. These proved to be in every way as good as steel box cars for fumigation purposes.)

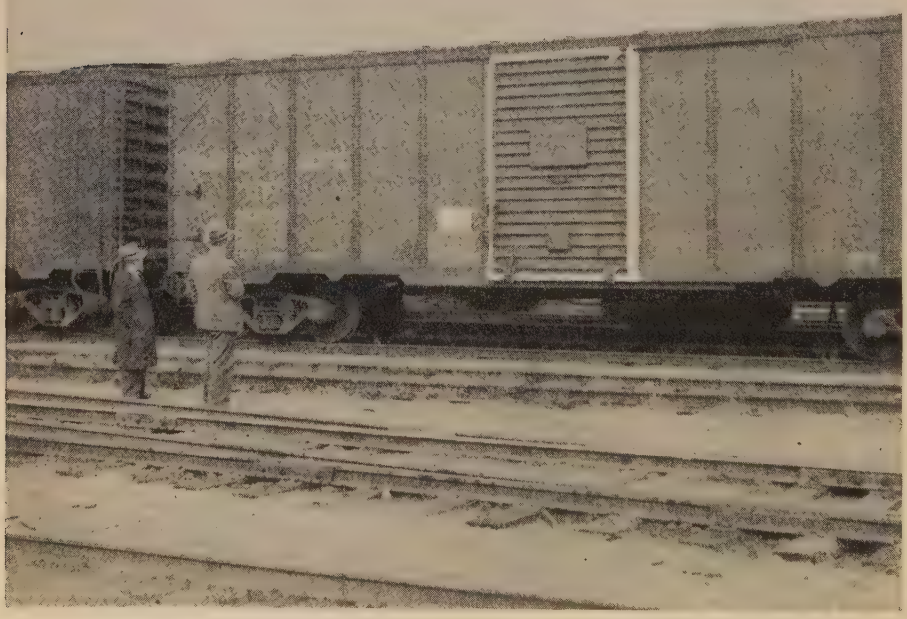

FIGURE 1. Canadian Pacific Railway freight car with plywood walls and steel roof. (Authors' photo).

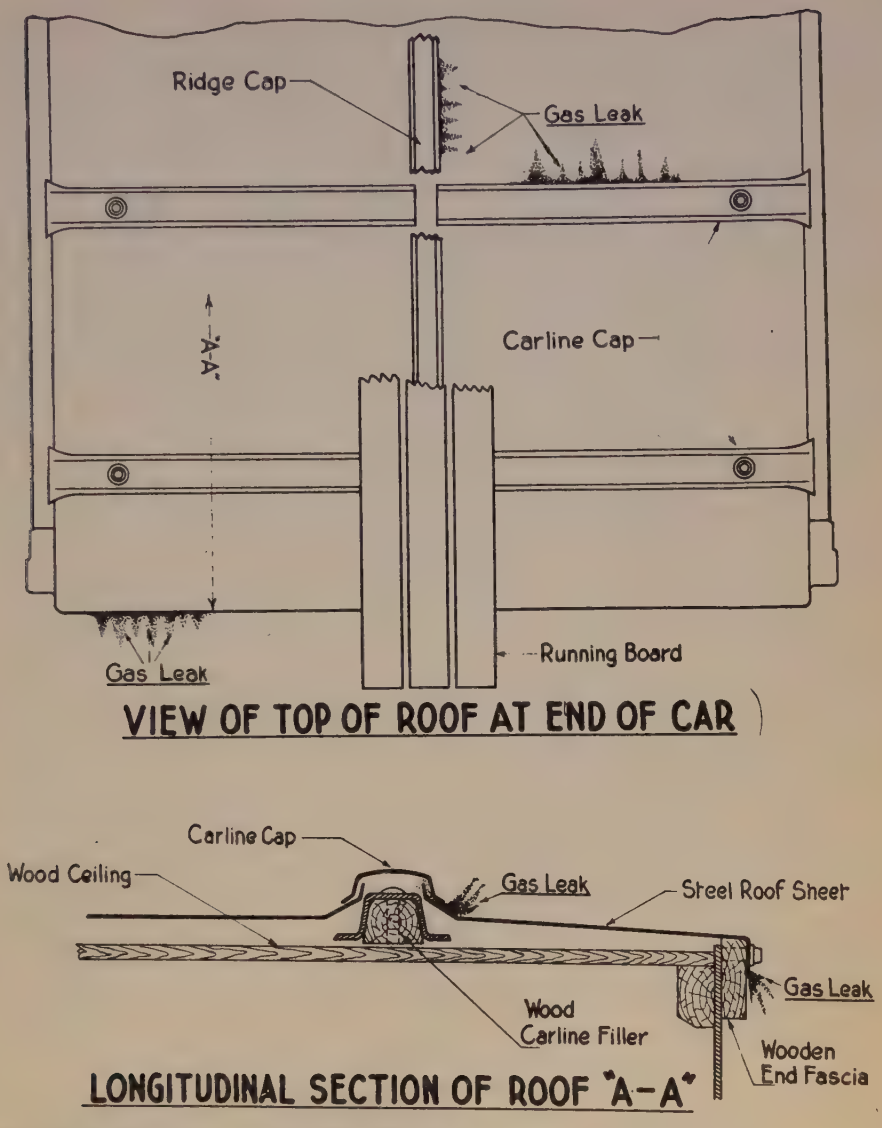

FIGURE 2

In "steel" box cars the walls and roofs are made of steel, but the floors are constructed with boards, usually British Columbia fir, 4 inches wide and $2\frac{1}{2}$ inches thick, joined by tongue and groove. Leaks of fumigants do not usually occur through the floors.

As a general rule, the air-tightness of a steel box car deteriorates with age, as constant vibration enlarges seams and cracks in the walls and roofs. It is therefore desirable to rule out, as far as possible, steel box cars more than 15 to 20 years old. Canadian steel box cars constructed approximately between 1927 and 1940 were equipped with types of all steel roofs known principally as "dry lading" or "radial" roofs.

These roofs, by the nature of their construction and the method of their attachment to the walls of the cars, will permit a considerable amount of leakage. The three types of roof construction encountered in these classes are illustrated diagramatically in Figures 2 and 3. The Canadian National Railways "radial" roof has transverse carline caps and a longitudinal ridge cap at the point of junction of the steel roof plates. At each end of the car, also, the end plate is bolted over a wooden sill or "fascia."

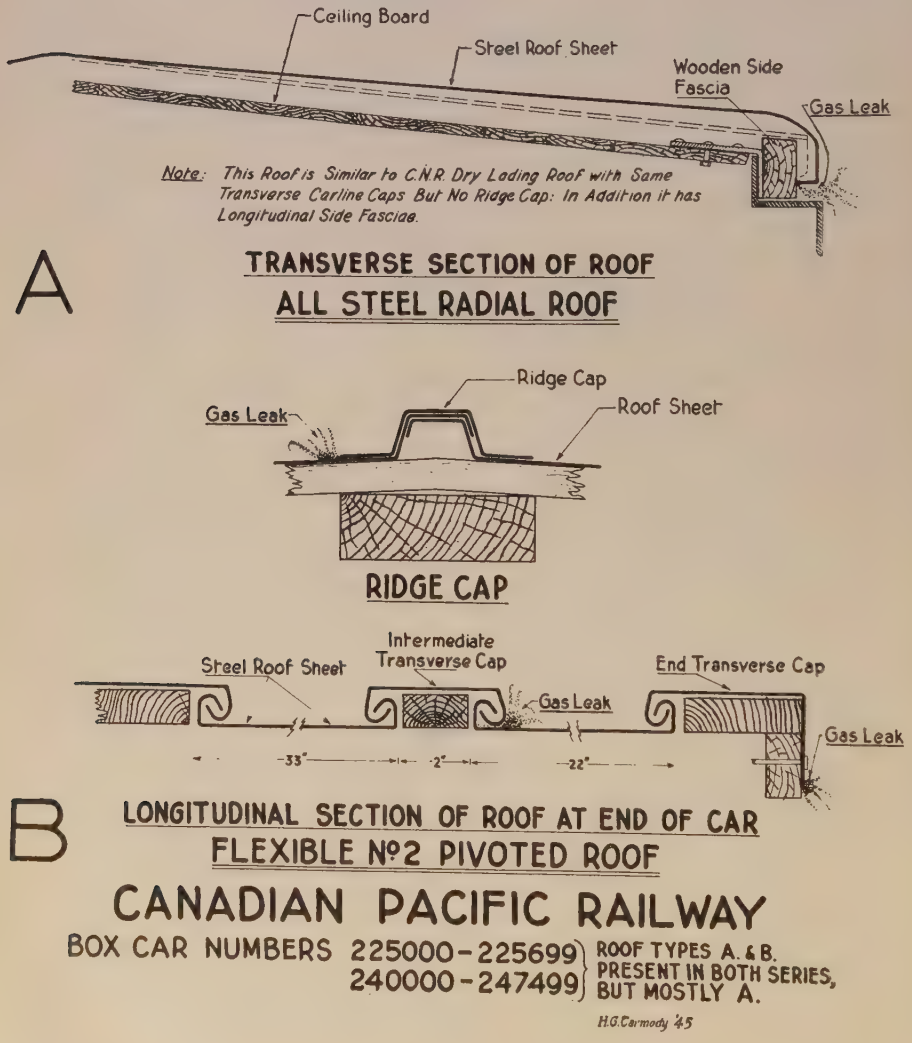

FIGURE 3

At both these points continual leakage of methyl bromide has been observed.[4] The "dry lading" steel roof of the Canadian Pacific Railway cars has transverse carline caps at the junctions of the steel plates, but these latter extend the full width of the car, and there is therefore no longitudinal ridge cap. This latter advantage is offset, however, by the fact that the roof rests on wooden fasciae at both sides and ends.

These roofs are also illustrated in photographs of the box cars in Figures 4 and 5. With continued wear and tear, warping and displacement

FIGURE 4. Older type Canadian National Railways steel freight car with wooden "fascia" at end of roof.

of the steel plates and the wooden fasciae occur to aggravate the amount of gas leakage. Pest control operators state that an additional four or five man-hours of work in sealing these cracks are required to render the cars fit for a satisfactory fumigation. As far as possible, the co-operation of the railway officials is solicited to avoid the use of these types of cars for conveying infested commodities requiring treatment (see Table 2).

The Canadian Pacific Railway "pivoted" roof (B in Figure 3) has never been encountered on all steel cars, although officials state that it is employed. It is common on wooden box cars with steel roofs. The great

[4] All these points of leakage were first demonstrated in actual practice during fumigations with methyl bromide with the aid of the commonly employed "Halide Leak Detector," various types of which are manufactured and marketed by different companies.

FIGURE 5. Older type Canadian Pacific Railway steel freight car with wooden "fasciae" at end and sides.

possibility of leaks through the intermediate transverse caps, which could not be easily sealed off, would seem to rule out from the beginning box cars so equipped.

TABLE 2.—CLASSIFICATION OF CANADIAN FREIGHT CARS

Listed by number series according to suitability for fumigation.

A. CARS WHICH SHOULD NOT BE EMPLOYED

(1) *All Wooden Box Cars.* (Some wooden box cars have been successfully employed, but a definite rule must be laid down to avoid them.)

(2) *All Automobile Cars.* (Even with considerable extra sealing, failures must be expected with this type.)

B. STEEL BOX CARS WHICH SHOULD BE AVOIDED, IF POSSIBLE, OWING TO CONSIDERABLE EXTRA SEALING REQUIRED

These cars have wooden sills (fasciae) at junction of wall and roof.

CANADIAN NATIONAL RAILWAYS

471000 – 473999, flexible all steel radial roofs.

CANADIAN PACIFIC RAILWAYS

225000 – 225699, flexible or pivoted steel roofs.
240000 – 247499, flexible or pivoted steel roofs.

C. Cars which can safely be employed

Canadian National Railways

474000 – 487764, plus new cars, riveted and welded steel roofs.
520000 – 521999, 50-ton capacity cars with riveted steel roofs.

Canadian Pacific Railways

221000 – 224449, riveted and welded steel roofs and plywood sheathed cars.
226000 – 228799, riveted and welded steel roofs.
248350 – 251249, plus new cars, riveted and welded steel roofs.

In recent steel freight car construction, mostly during the last four or five years, both Canadian railway companies have employed all steel roofs, described either as the "riveted roof" or "solid steel roof." An example of this roof is illustrated in Figures 6 and 7. The steel plates are riveted or welded together and the seams filled with a caulking compound. The entire roof is then riveted and caulked onto the walls, so that an airtight structure is produced. The number series of these new types (to recent date) are given in Table 2. These cars are so well made that they form perfect fumigation structures and, if thoroughly sealed, the amount of gas leakage from them appears to be practically nil, so that a constant minimum dosage can be safely employed.

Figure 6. New type riveted steel roof as used on Canadian National Railways steel freight car (see Figure 7).

FIGURE 7. New type steel freight car with all steel roof.

In our experience steel freight cars owned by railways in the United States and which have been used while in Canada have not, on the average, been so suitable for this type of work. This has been due, for the most part, to the fact that American cars seen in this country have been both considerably older, dating many of them prior to 1929, and subjected to more wear and tear. A number of recently built cars, similar to the Canadian all steel car with the riveted roof, have been encountered, proving to be as suitable as the most recent Canadian types.

FUMIGATION METHODS

Fumigant Employed

In all this work methyl bromide was the fumigant employed, either alone or in combination as a proprietary fumigant containing approximately 93% carbon dioxide and 7% methyl bromide.

Methyl bromide (CH_3Br) at ordinary temperatures is an odourless gas, boiling from a colourless liquid at 40.1° F. and having a specific gravity (Air = 1.00) of 3.27 at 32° F. It is thus considerably heavier than air. The molecular weight is 94.94. Experience has shown that it tends to stratify if introduced at the lower part of a fumigation structure, but once thoroughly mixed with air by fan circulation or diffusion it remains in equilibrium with all parts of the atmosphere of the structure. It is lost very rapidly through any point of leakage.

Methyl bromide alone is supplied in 1-pound cans or cylinders of different weights. When mixed with carbon dioxide it is usually marketed in cylinders containing 50 lb. of the mixture.

The natural vapour pressure in methyl bromide containers is: at 50° F.—4 lb. per square inch; 60° F.—8.5 lb.; 70° F.—13 lb.; 80° F.—19 lb.; 90° F.—25 lb.; 100° F.—32 lb.

Sealing the Cars

In box car fumigation considerable care and thought must be given to the extra sealing required, to prevent avoidable leakage of the gas. Methyl bromide is very volatile and quickly diffuses through any leaks in the structure. As already pointed out, in the best type of steel box cars sealing in the region of the doors is all that is required.

Experience has shown that the best method is to seal both doors from the outside, so that every point of leak detected round the sealing is accessible after sealing is completed. Many insects attempt to escape from the gas by crawling into cracks in the floor and under the door, and outside sealing ensures both that the fumigant is able to penetrate these cracks and also that the insects are unable to reach the outside air. In addition to sealing round the doors it is also necessary to seal off small leaks around the rollers of the door tracks. Other points of leak may be encountered from time to time, such as rain drainage outlets found in some types of cars.

Under normal conditions effective sealing can be done with brown paper liberally smeared on both sides with a good quality casein paste or one containing a mixture of flour and oil. A sticky mineral jelly such as vaseline (petrolatum) has been used to stick down the paper, and this is especially useful at lower temperatures, but it is necessary to wipe the surface afterwards to remove the jelly to prevent accidents liable to be caused by the slippery surface. Other methods have been successfully employed at the discretion of the individual operators, including the use of a mixture of calcium chloride and asbestos.

Before the war masking tape was usually recommended for convenience, but at the time of writing it is difficult to obtain.

Applying the Fumigant

As the whole treatment was placed in the hands of the commercial operators, the methods of applying the fumigant were left largely to their individual choice. Actually, for the reasons discussed hereafter, this Department would prefer the employment of a method by which the gas is applied from outside the car.

"Cold Gas" and Pan Method: The methyl bromide in 1-pound cans is cooled off with dry ice until it is at a temperature well below its boiling point. Two operators, wearing gas masks and either leather or rubber gloves then enter the car through one door, the opposite door having already been sealed either on the inside or, preferably, the outside. Each man working from one end of the car, the cans are opened with special openers ("beer can openers") and the contents poured into shallow dishes or baking pans, placed at intervals on top of the bags, until the required

dosage is obtained. The open door is rapidly closed and sealed after the operators withdraw (Figure 8). This method has been found very effective for obtaining complete control of the insects as long as the pans are placed near the highest points of the bags. Apparently the majority of the gas

FIGURE 8. Sealing freight car after application of fumigant.

remains for some time at a low level in the cars, as failures have so far not been reported in the cars with the wooden fasciae described above. Unfortunately, the cooled cans are too cold to be carried in the bare hand and, when gloves are worn by an operator treating a fair number of cars per day for several continuous days, typical "methyl bromide" blisters develop on the thumbs and fingers of the men. These are irritating and take some time to heal up. The formation of these blisters is due to the absorption and retention of methyl bromide in the fabric of the glove.

"Hot Gas" Method: In this case the procedure is similar to that in the foregoing method, but the cans are not cooled and the operator does not usually wear gloves. Usually, also, pans are not used, but if they are they merely serve as a platform on which to set the cans. The cans are opened with can openers or sharp chisels, and immediately a mixture of gas and liquid is forced out of the can, and on warm days this effect is greatly increased. It is impossible to avoid the spilling of some of the liquid on the fingers and here again blisters develop on the hands if more than a few cars are treated. Some operators prop the cans carefully between two bags, others merely stand at the door and throw them towards the end of the cars.

With this method serious leaks of fumigant and failures to obtain control have resulted when used with cars equipped with the roofs balanced on the wooden fasciae, and extra sealing is required to avoid this. Moreover, with the leak detectors tests have shown that some methyl bromide is lost to the open air before the open door can be shut. This method, therefore, is open to very serious objections and should be avoided, especially when a large number of cars are undergoing treatment.

"Can and Applicator" Method: Special applicators (see Figure 9) can be obtained for discharging methyl bromide from the 1-pound cans. By means of a steel spring which binds the can, a pointed steel tube surrounded

FIGURE 9. Use of methyl bromide cans to apply fumigant from roof, especially useful in cool weather. (Authors' photo).

by a rubber gasket is thrust into the can and the liquid forced out by the gaseous pressure inside the can. Recently "Saran" plastic tubing has been introduced for carrying the fumigant to the point of discharge. These tubes are closed at the end with a copper thread and have small holes punched near the tip to allow the lateral discharge of the fumigant.

As illustrated (Figure 9) a convenient method of using this apparatus is to mount three applicators on a small wooden platform to steady the cans against the back pressure of the gas. If the cans are discharged from the top of the car residual gas and liquid in the line drains off more readily, especially in cool weather. One operator devised a method (see Figure 10) of holding the door practically closed by means of a wooden board 4 inches

FIGURE 10. Roof application of methyl bromide, showing position of board in door. (Authors' photo).

wide placed in the door jamb, leaving a small aperture 6 by 4 inches in area at the top through which the tubes led into the car. The door could then be quickly sealed after the removal of the board.

Saran plastic tubing becomes somewhat brittle when cooled to about 32° F., and it is invariably cooled by the methyl bromide vapour discharging through it. Some care, therefore, must be exercised in handling it under these conditions.

Cylinder Methods: The unmixed methyl bromide can be very readily discharged from cylinders by the positive pressure of the fumigant itself, which is usually increased by the addition of some air before shipment.

By attaching an ordinary copper tube of, preferably, 3/16-inch internal diameter directly to the cylinder (Figure 11) the gas can be carried into the car through a small hole bored in the floor near the door or through the aperture above the board as described in the preceding section (Figure 10).

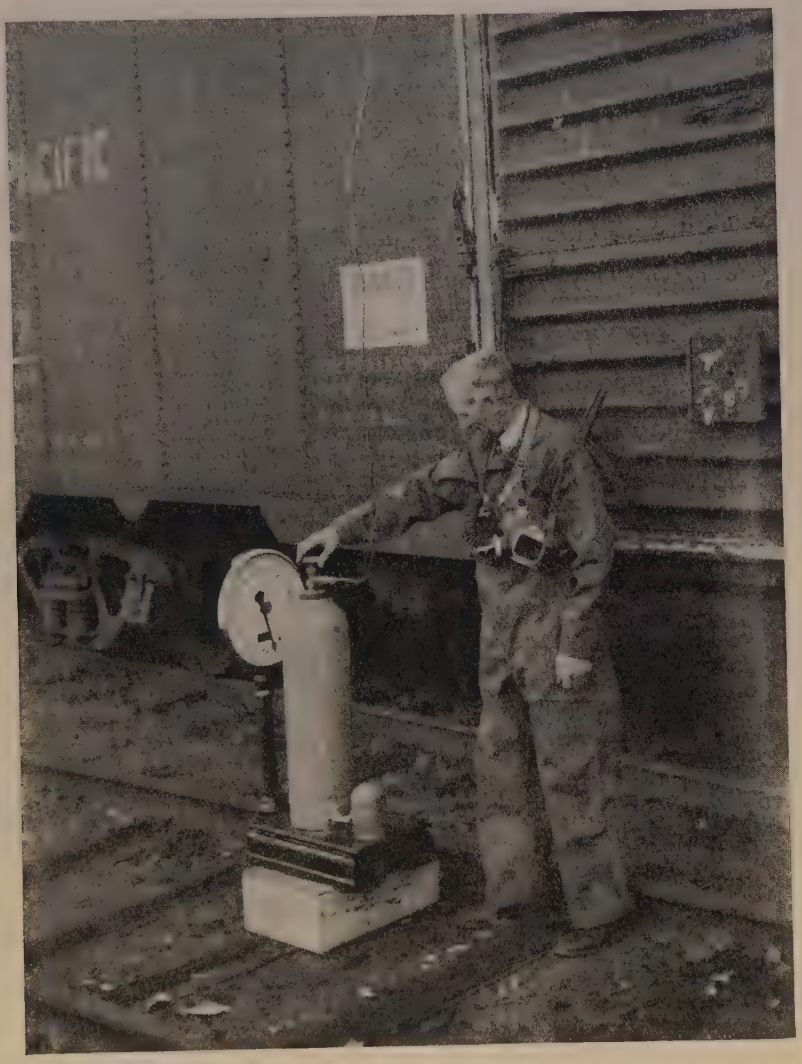

FIGURE 11. Cylinder method of methyl bromide application. (Authors' photo).

After discharge the hole in the floor should always be carefully filled with a hardwood plug whittled to the correct size. The copper tube should be pinched at the end and several small holes punched near the tip for side delivery of the fumigant. The weight of fumigant required is easily read on the scale holding the cylinder.

In many ways this is the most satisfactory and safest method of discharging the gas, and is the one preferred for recommendation by this

Division. However, operators have found the cylinders and scales heavy and awkward to move around in a railway freight yard, and, during recent years, there has been a shortage of cylinders.

The proprietary fumigant "Proxate" is discharged from 50-pound cylinders containing approximately 3.5 lb. of methyl bromide and 46.5 lb. of carbon dioxide. It is claimed that the carbon dioxide adds to the effectiveness of the fumigant, permitting lower doses of methyl bromide. This effect has never been confirmed by us in practical application, but there is no doubt that the carbon dioxide aids in the rapid diffusion of the toxic agent. However, in cars which are liable to leak, especially through the roof, failures have been recorded. This matter is discussed more fully under "Results." "Proxate" is usually discharged through holes bored in the floor of the car, so that both doors can be fully sealed before application. In very tight cars this fumigant mixture can often be observed discharging excess pressure by distending the paper sealing material, and thus sometimes some re-sealing is required. The entire contents of the two cylinders are discharged for each car, giving a dose of approximately 7 lb. of methyl bromide per car.

VENTILATION AND INSPECTION

The fumigation treatments were invariably made overnight, with exposure periods of 16 to 24 hours. At the end of treatment both doors were opened wide and the cars were not entered for at least two hours. Under most summer conditions this was sufficient for the dissipation of the gas from the body of the car, and only mild reactions for methyl bromide of approximately 50 parts per million were recorded among the bags towards the end of the cars. As might be expected, weather conditions influenced the ventilation of the gas considerably, and a number of different effects were observed, the more important of which are listed herewith:

(1) On warm windless days the gas dissipated rapidly from all parts of the cars and most quickly in the absence of extensive cloud cover.

(2) On very windy days, either cold or warm, when a strong draught of air crossed the middle of the cars, the gas was sometimes "pocketed" at one or both ends of the cars.

(3) In cool damp weather and during rain the gas took often considerably more than 6 hours to dissipate completely from the free air space in the cars. In Vancouver, B.C., during the night October 2nd to 3rd, rain and fog was continuous and there was no wind. A car of peanuts under observation was opened up at 2.00 p.m. on October 2nd when the outside air temperature was 56° F. and that in the free air space of the car 62° F. During the night these fell to 58 and 53° F., respectively and rose to 59° in both cases when due for inspection at 2.00 p.m. on October 3rd. The temperature in the peanuts was 65° F. 22 hours after opening. At this time the rain and fog were still prevailing. Tests with the leak detector showed methyl bromide present in the free air of the car to be 35-50 parts per million only 4 to 6 feet back from the opened doors, 24 hours after both doors had been opened.

The above examples demonstrate most forcibly the danger of following any hard and fast rules for natural ventilation. Climatic conditions, with their attendant air currents, have a very marked and variable effect. The

inspectors of this Division have instructions to protect themselves with careful and frequent use of the leak detector before entering cars to carry out inspections, as it is not considered practical or necessary for them to wear gas masks for this work. In practice, the examination of the commodity for insect kill is usually made at or near the doors, as these are the weakest points in the fumigation structure.

In no instance were the cars released for dispatch for destination until they had received at least 6 hours of continuous ventilation.

During 1944 each car of produce was examined by an inspector of this Division before being released. Some samples of peanuts from each consignment were also taken before and after treatment for checks on quality and residue. These matters are discussed further under "Results."

RESULTS

During 1944 a total of 873 freight cars were fumigated with methyl bromide under the supervision of this Department (see Table 1). Of this number 94 were cars of broom corn treated at low temperatures and in which only test insects were employed to estimate the mortality obtained. The broom corn treatments are being made the subject of a separate report.

Mortality of Insects

Of the balance of 781 cars which were used to treat peanuts, chick peas, wheat and cotton seed meal only 15 treatments were rejected for failure to produce a satisfactory kill of the insects found in the produce.

In assessing a "satisfactory kill" the inspectors were, theoretically, allowed to exercise some judgment. For example, the finding of one or two live insects in a heavily infested carload would not necessarily cause a rejection. In practice, however, rigorous inspection of the cars usually failed to reveal any living insects after the successful treatments. In the case of the failures, numerous survivors were always found.

In warm weather the insects were sometimes found in considerable numbers on the outside of the roofs and walls. These insects could, and did, migrate back into the cars during the ventilation process. Also, occasionally, insects were found flying from cars awaiting fumigation, and undergoing sealing, to cars being ventilated on an adjacent track. These movements back into ventilated cars seemed to be confined to a very small number of individuals and were of no consequence as they were not responsible for any fresh outbreaks of the pests.

On arrival of a few of the cars at destination complaints were made by the consignees following the finding of live insects on the commodity. On investigation it was found that only a few insects were involved and apparently they had moved back into the fumigated cars in the manner described above.

Cotton seed meal tends to pack very thickly in the bags, and it was thought that some difficulty might be encountered in gaining penetration. However, with a dose of 2.5 lb. per thousand cubic feet and a 36-hour exposure at summer temperatures complete control was obtained in the cars.

The record of 15 failures includes 13 due to unsatisfactory cars, a situation which, in view of wider experience, could be avoided by additional sealing of those cars which can be made more airtight or by rejection of cars now known to be structurally unsuitable for fumigation under any circumstances. The two failures due to faulty method came about through the use of the 1-pound cans and the Saran plastic tubing by an operator who was not familiar with their use. Here again additional experience will obviate such failures.

FIGURE 12. Freight car loaded with peanuts, after fumigation.

From 53 of the cars of peanuts successfully fumigated and passed by our inspectors at Montreal (43 cars) and Vancouver (10 cars) 2-pound samples of peanuts were taken to the laboratory and incubated at 80° F. and 60% relative humidity, suitable for rapid development of the species involved. These samples were examined periodically and in only three cases were insects found to develop. Two were from United States cars of doubtful construction treated with the proprietary mixture, and showed a development of *Tribolium castaneum* Herbst. The other was a sample from a sound car treated at Vancouver which showed complete mortality of all stages of *T. castaneum* and eggs and larvae of *P. interpunctella* but in which the only cadelle larva (*T. mauritanicus*) found was a survivor. Control samples removed before treatment showed continued development of the populations. These results coupled with observations made during unloading and storage tend to show that all stages of the insects listed above can be killed during a successful freight car fumigation in a satisfactory type of car.

Effect of Dosage

As already stated, the dose of fumigant and the methods of applying it were left to the judgment of the individual pest control operator. At the beginning of the project, when less was known about the sources of leak and the methods of overcoming them, an over all dose of 10 lb. of methyl bromide for a car of 3,710 cubic feet capacity (approximately 2.5 lb. per thousand cubic feet) was made for treatments with the temperature above 60° F. in both commodity and free air space. With the cars of the best type, as described above, it was found that 6 lb. per car was sufficient to give a complete kill (approximately 1.5 lb. per thousand cubic feet). Very few treatments were made at lower temperatures, but the operators concerned added ½ pound per thousand cubic feet for every 5-degree drop below 60° F., based on the temperatures at time of application. These doses were usually employed for an exposure of 16-24 hours except in the cars of the cotton seed meal where a 36-hour exposure was given.

Effect of Temperature and Outside Weather Conditions

During the period May to November, 1944, a fairly wide range of temperature conditions was encountered. The lowest temperatures were experienced during the treatment of chicory root to control *Plodia interpunctella* larvae at Halifax on October 30. The temperatures experienced were: Commodity 46-50° F.; in free air of car 32° minimum during night, 50° maximum during day; in outside air 38° maximum, 24° minimum during the night. The period of exposure was 21 hours and the dose of methyl bromide 3 lb. per thousand cubic feet. Careful examination revealed that complete control of all the larvae had been obtained, including those boring deeply into the roots. In the fumigation of peanuts temperatures as low as this were not encountered, but successful fumigations were done at commodity temperatures as low as 52° with outside temperatures of 45° and car temperatures as low as 54° F. From the results of other investigations on low temperatures (as yet unpublished) it is believed that successful results can be obtained at commodity temperatures as low as 20° F. (and possibly lower) as long as the problems of volatilizing the gas can be overcome.

With full sunshine beating on the walls and roofs of the cars, inside temperatures as high as 107° F. have been observed.

Wind velocities as high as 20 miles per hour were recorded during the fumigations. It is concluded that, as a result of extended observations on this point, wind velocity has no effect on the success of freight car fumigation, provided good cars and adequate sealing are employed.

Effect of Fumigation on the Commodities

No complaints of alteration in taste or processing qualities were received as the result of the fumigation with methyl bromide of imported peanuts and cotton seed meal, and exported chicory, wheat, and chick peas. In the case of the peanuts, manufacturers of peanut butter were contacted in several cities and the statement elicited that the fumigant had had no appreciable effect on taste. Tests in the Fumigation Laboratory at Montreal, P.Q., made on the chicory also failed to show any effect on the flavour of ground chicory.

Samples of peanuts removed from the cars after fumigation were submitted to the Dow Chemical Corporation, Midland, Michigan, for analysis in their laboratories. The results of this analysis are given in Table 3. The first sample of American peanuts was obtained during the

TABLE 3.—RESIDUES IN PEANUTS FUMIGATED WITH METHYL BROMIDE IN FREIGHT CARS

Sample	Total bromide	Remarks
	%	
American peanuts Car CN 476533, 3,712 cu. ft. containing 65 bales of broom corn. Dose—16 pounds of methyl bromide for 20 hrs. Temperature—25° F. in bag peanuts.	0.0028	
Control, non-fumigated	0.0001	
Nigerian peanuts 100 lbs. Proxate, May 20, 24 hrs., 3,000 cu. ft. commodity at 64° F., NYC 130440	0.0010	
10 lbs. methyl bromide in pans, 24 hrs., May 20, commodity at 65° F., C & O 12533, 3,000 cu. ft.	0.0009	
First fumigation, Erie 70927, 2,926 cu. ft., 10 lbs., CH_3Br with applicator, May 19, 24 hrs. at 60° F. Second fumigation, CP 221264, 3,715 cu. ft., 100 lbs., Proxate, 24 hrs., May 24 at 64° F.	0.0015	Repeat due to failure in application.
Control, non-fumigated ex WAB 82361	0.0004	

fumigation of broom corn at low temperatures. The figures obtained are somewhat lower than those quoted by Dudley and Neal (2) for whole nut, unroasted peanuts. These authors exposed peanuts and other products to a dosage of two pounds of methyl bromide per thousand cubic feet for 24 hours at 68-77° F. and obtained the following residues in the peanuts:

Mg. Br./100 gm. sample

Sample	Before fumigation (control)	Immediately after fumigation	24 hours after fumigation	48 hours after fumigation
Peanuts, whole nut, unroasted	None	5.04	5.00	5.00
	Expressed as percentage total bromide			
	0	.00504	.0050	.0050

None of these residues, however, can be interpreted as of any significance from the point of view of human consumption, according to observations made by Dudley and Neal (2), Flinn (3) and Clark *et al.* (1).

SUMMARY

1. A description is given of a successful campaign to prevent the spread of stored product insects found in imported plant products. The infestations were eliminated chiefly by fumigation with methyl bromide in steel freight cars at the port of importation or at destination.

2. An account is also given of freight car treatments of exported foodstuffs prior to loading on board the steamship.

3. With the selection of suitable types of steel freight cars satisfactory control of several species of stored product insects was obtained in shelled peanuts, wheat in bags, chick peas, and cotton seed meal. In most cases complete mortality of all the insects present was obtained.

4. The methyl bromide fumigation appeared to have no adverse effects on the products treated and residues analysed in fumigated peanuts were of no toxicological significance.

5. For steel freight cars of airtight construction a dose of 1.5 lb. of methyl bromide per thousand cubic feet is recommended for exposure periods of 16 to 24 hours at temperatures of 60° F. and above. A graduated increase in dose for lower temperatures is provisionally suggested.

ACKNOWLEDGMENTS

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The data on which this paper is based were gathered by the district inspectors and their staffs in the offices of the Division of Plant Protection in the districts throughout the country where freight car fumigations were carried on. The district inspectors concerned were: Messrs. R. G. Webber, Halifax, N.S.; A. Finnamore, Saint John, N.B.; L. R. Gagnon, Quebec, P.Q.; W. St. G. Ryan, Montreal, P.Q.; A. Fowler, Toronto, Ont.; F. J. Hudson, London, Ont.; and H. F. Olds, Vancouver, B.C. In addition valuable suggestions and observations were made by Messrs. A. E. McCollom and W. S. Hoar of the Saint John office.

The representatives of the fumigating companies doing this work under our supervision were also very helpful in arranging their treatment schedules to enable us on many occasions to gain special data and take photographs. In this connection we would like to mention Messrs. G. Worth of the Pestroy Co. Ltd., Montreal, P.Q.; E. J. Gentle of the Pest Control Service, Hamilton, Ont.; J. C. Otis of the Mysto, Inc., Montreal, P.Q.; W. R. Beatty of the Johnston National Storage Ltd., Vancouver, B.C.; and H. W. Johnson of Canadian Service and Sales Co., Verdun, P.Q.

Blueprints showing the construction of various types of cars were loaned by officers of the equipment departments of the two principal Canadian Railway companies, who also supplied important data and lists of car series. These officers were, for the Canadian National Railways, Mr. E. R. Battley, Chief of Motive Power and Car Equipment, and Mr. G. E. McCoy, Assistant Chief of Car Equipment, and for the Canadian Pacific Railway Company, Mr. H. B. Bowen, Chief of Motive Power and Rolling Stock, and Mr. H. B. Winship, Mechanical Engineer.

We are indebted to Mr. H. G. Carmody of the Toronto Office of this Division for preparing the illustrations for Figures 2 and 3.

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THE RETENTION OF NUTRIENTS IN CHEESE MAKING

I. THE RETENTION OF CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN CHEDDAR CHEESE MADE FROM RAW MILK[1]

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Cheese of the cheddar variety was one of the first dairy products manufactured on a commercial scale in Canada. Since its inception the cheese industry has served as the chief means whereby Canadian dairymen have been able to conserve and market much of the milk produced during the seasons of heavy production. Cheese manufacture has continued to maintain this position of leadership in spite of the fact that more modern methods of preserving the nutrients of milk have since been perfected.

It is recognized that in the cheese making process, a portion of the milk nutrients is not retained. The nutrients which are not retained consist chiefly of lactose and albumin as well as relatively large proportions of the minerals and water-soluble vitamins. Whey, the by-product of cheese making, is utilized largely in the feeding of farm animals and this fact, in conjunction with the relatively low cost of manufacturing, tends to compensate for these losses.

While the proportions of these constituents which are lost in the whey are comparatively great, the retention efficiencies for fat, casein and vitamin A are relatively high, with the result that cheddar cheese is generally listed as an excellent source of these nutrients. However, no data appear to exist for calcium and phosphorus retention in Canadian cheese. Furthermore, retention of the B-complex vitamins has not been a subject of extensive study.

It was for these reasons that this project was undertaken. In it, a study has been made of the proportions of the calcium, phosphorus and riboflavin which are lost in the whey and retained in the cheese when unpasteurized milk is manufactured into Canadian cheddar cheese. The stability of the riboflavin throughout a ripening period of twelve months has also been determined. In addition, data are presented on milk and cheese obtained from four different soil areas of Southern Ontario. A number of samples of cheese displaying flavour defects are also reported on.

The study has been carried out as a co-operative project and joint contribution between the Ontario Agricultural College, Guelph, and the Department of Pediatrics, Hospital for Sick Children, University of Toronto.

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[1] Joint contribution from the Departments of Dairying and Chemistry, O.A.C., and the Department of Paediatrics, Hospital for Sick Children, Toronto. Determinations for fat and total solids were made in the Dairy Chemistry laboratory, O.A.C., while those for calcium, phosphorus and riboflavin were made at the Hospital for Sick Children.

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HISTORICAL

McCammon, Caulfield and Kramer (9) have reported on the calcium and phosphorus contents of American cheddar cheese made under controlled conditions. Their values indicated that 80% of the calcium and 38% of the phosphorus originally present in the milk, were retained in the cheese. Approximately 85% of the phosphorus was accounted for by the protein. The method of manufacture influenced the retention of calcium in that increasing the acidity at rennetting resulted in increased losses of calcium in the whey.

Mattick (11), reporting on English cheddar, found that 65-68% of the calcium and 51-60% of the phosphorus were retained. Practically the whole of the mineral loss took place at the time the whey was run.

McDowall and Dolby (10) state that for New Zealand cheese, in normal operations 60% of the calcium and 57% of the phosphorus are retained. The mineral content of the whey increased steadily as the process of manufacture advanced except for a temporary fall after salting. Zahrndt, Lane and Hammer (18) studied the calcium, phosphorus and calcium/phosphorus ratios of a number of cheddar cheese samples from Iowa, Wisconsin and New York and concluded that differences in these values are only such as might be attributed to sampling variations.

Studies on the vitamin content of cheese aside from some of the fat soluble vitamins, have been quite limited. In the case of the cheddar variety Houston and Kon (4) give a value of 310 μg. of riboflavin per 100 grams in a preliminary report while Munsell (12) found that American cheddar contained 545-600 μg. per 100 grams. Day and Darby (3) were among the earlier workers to recommend American cheddar as a source of this vitamin. Sullivan, Bloom and Jarmol (16) found that variations in the riboflavin content of Limburger cheese during ripening, were less marked than for the other vitamins of the B group.

EXPERIMENTAL

In order to secure as reliable a picture as possible of the retention and losses of these nutrients in the cheese making process, the experimental program was extended over a full year, while an additional 12-month period was required to complete the ripening of the last batch of cheese. In addition a small number of samples was secured at different points in Ontario with a view to determining whether or not the regular experimental results were of the same order as those prevailing at commercial plants.

The procedure in the main experiment consisted of manufacturing approximately 1200-1800 pounds of milk into cheddar cheese using the recognized commercial technique as commonly practiced for this variety. A vat was made up each month during the period May, 1942 to April, 1943. The resulting cheese from each batch were divided into two lots, one of which was ripened at 40° F. while the other was ripened at 58° F. Samples were taken at intervals until the cheese were one year old.

The milk used in the study was secured from the College herd which consists of Holstein, Jersey and Ayrshire breeds. On one or two occasions it was necessary to supplement this supply with a small amount from an

outside source. All the milk was regularly of good quality. While experimental manufacturing operations extended over a year, every effort was made to maintain the greatest possible uniformity in manufacturing conditions.

Two samples of the milk plus starter were secured in 8-oz. amber bottles after thorough mixing. Similar samples of the "first" whey and "press" whey were also secured. The term "first" whey, as used in this study, includes all the whey which drained from the curd during running and stirring as well as that which continued to drain from the curds until they were cut and turned the second time after piling. "Press" whey includes all the brine which drained from the curd after salting as well as that which was expressed from the cheese in the press up to the time of dressing the cheese. The weight of the first whey was estimated by measuring it in a calibrated cylindrical tank while the weight of the press whey was determined by weighing.

The curds were pressed into Stilton-shaped cheese of approximately 10 pound each. On the morning following manufacture, three of these were cut in halves, the resulting 5-lb. pieces being used for scoring. The procedure followed for sampling the cheese for analysis in this as well as for subsequent series, consisted of removing the outer rind plus an additional slice of cheese approximately 2 cm. thick from the end of a 10-pound cheese. A second slice was then taken of approximately the same thickness. This disc was then cut into wedges, two of which were wrapped in moisture-proof cellophane and forwarded to each of the laboratories for analysis.

As soon after sampling as possible, the cut surfaces of the cheeses were re-paraffined, thus allowing the same cheese to serve as a source of material for subsequent sampling. The details of sampling and analysis on the milk, whey, and cheese are shown in Table 1.

TABLE 1.—SCHEDULE FOR SAMPLING AND ANALYSIS OF MILK, WHEY AND CHEESE

—	Milk	First whey	Press whey
Fat	x	x	x
T.S.	x	x	x
Ca	x	x	x
P	x	x	x
Ribo	x	x	x

Cheese (ripened at 40° F. and 58° F.)

—	Age—1 da.	14 da.	1 mo.	2 mo.	3 mo.	4 mo.	6 mo.	8 mo.	10 mo.	12 mo.
Fat	x	x	x	x	x	x	x	x	x	x
T.S.	x	x	x	x	x	x	x	x	x	x
Ca	x									
P	x									
Ribo	x	x	x	x	x	x	x	x	x	x

METHODS OF ANALYSIS

Preparation of Sample for Total Solids and Fat Determinations

Approximately 3 mm. was removed from the outside edge of the sample (sufficient to remove all the cheesecloth and a small portion of the rind). The sample was then passed through a food grinder, of the ordinary kitchen type, three times, and transferred to an air-tight, screw cap bottle. This procedure was completed as quickly as possible to insure a minimum loss of moisture.

Total Solids Determination

An aluminium dish 55 mm. in diameter and 15 mm. in depth, provided with a slip-in inverted cover fitting tightly on the inside was used. Two to three grams of the sample was weighed into the previously heated and weighed dish, covered tightly and reweighed. The lid and dish were then placed separately in a cool oven, heated to 100° C. and held at that temperature for 24 hours. The cover was then replaced, and the dish cooled and weighed again. Each sample was done in duplicate.

Fat Determination

The standard Mojonnier procedure for fat determination on cheese was used throughout, and each sample was treated in duplicate. Approximately one gram of the ground cheese was introduced into a previously weighed Mojonnier fat flask, stoppered tightly and reweighed. Eight ml. of hot water was added and the flask thoroughly shaken. Three ml. ammonia solution was then added and the flask thoroughly shaken again. At this point it was necessary to make certain that all cheese was thoroughly dispersed. Then 10 ml. alcohol, 25 ml. ethyl ether and 25 ml. petroleum ether were added, shaking one-half minute after the addition of the alcohol, and 20 seconds after the addition of the two ethers. The flasks were centrifuged for 30 turns in one-half minute. The ether layer was then poured off into a heated and weighed fat dish and evaporated to dryness. The second extraction was then carried out in the standard manner. This method for the determination of fat gives somewhat low results as compared with Official Methods (2).

Calcium

The samples were ashed at 550° C. under sodium carbonate. The ash was taken up in nitric acid, diluted to a definite volume and filtered. The calcium was determined in an aliquot of the filtrate by precipitation as calcium oxalate and titration with potassium permangante by the method of Kramer and Tisdall (7).

Phosphorus

An aliquot of the ash solution used for the calcium determination was evaporated with a small amount of concentrated sulphuric acid and heated until fuming to expel the nitric acid and hydrolyze any pyro-phosphates present. After dilution, the phosphorus was determined colorimetrically, using the Evelyn photo-electric-colorimeter.

Riboflavin

The cheese sample was ground and a suitable aliquot was weighed out. This was mixed with 50 ml. of 0.1 N H Cl and autoclaved at 15 lb. steam pressure for ½ hour. After cooling, 1 ml. of 2.5 M sodium acetate was added and the pH adjusted to 6.8. It was filtered and the precipitate re-extracted with 25 ml. of N/10 H Cl, cooled, the pH adjusted to 4.5 and filtered. The precipitate and filter were then washed with water several times and the combined extracts and washings adjusted to pH 6.8 and diluted to 200 ml. volume.

The riboflavin in the extracts was determined by the Snell and Strong microbiological assay method, used without modification (15).

Preparation of the extract in this way was found to eliminate interfering fatty materials by entrapping them on the voluminous precipitate that formed at pH 4.5. Preliminary removal of the fats by ether extraction of the cheese did not affect the results.

RESULTS

As an indication of the methods followed in handling the curds in this study, Table 2 presents the pertinent values which were obtained in the cheesemaking process.

TABLE 2.—DETAILS OF THE CHEESE-MAKING PROCESS

Date of mfg. and lot number		Starter	Milk ripening period	Setting acidity	Set to run	Running acidity	Run. to salt
		%	— min.	%	— min.	%	— min.
26/5/42	1	1.0	50	0.195	155	0.18	230
29/6	2	1.0	96	0.185	134	0.185	220
27/7	3	1.0	90	0.18	160	0.18	225
26/8	4	1.0	72	0.185	188	0.185	180
30/9	5	1.25	75	0.19	155	0.18	255
20/10	6	1.50	65	0.19	120	0.19	190
19/11	7	1.25	72	0.185	178	0.20	190
15/12	8	1.0	71	0.19	178	0.18	240
18/1/43	9	1.4	94	0.175	201	0.175	190
24/2	10	1.5	85	0.18	170	0.185	185
16/3	11	1.5	80	0.175	160	0.175	225
21/4	12	1.0	115	0.185	160	0.175	205

Rennet extract was used at a rate of 3 fl. oz. per 1000 lb. milk.
Salt was added at a rate of 2.25 lb. per 1000 lb. milk.

It will be observed that variations occurred in the amount of starter employed, in the setting and dipping acidities as well as in the lengths of times the curds were in the whey. These variations are to be expected over a full year and were necessary in order to secure good quality cheese.

Retention of Calcium in Cheese

In order to increase the clarity of this presentation, many of the data have been tabulated and are presented in an appendix. (Tables 10, 11 and 12). The efficiency of the cheesemaking process as a means of retaining these nutrients, has been ascertained by calculating the percentage of

the nutrient originally present in the milk which is accounted for in the cheese. In the case of calcium these values are presented in Table 3.

TABLE 3.—LOSSES AND RETENTIONS OF CALCIUM IN CHEDDAR CHEESE-MAKING

Lot No.	First whey	Press whey	Cheese	Total
	%	%	%	%
1	36.5	0.68	60.5	97.7
2	43.5	0.9	57.5	101.9
3	42.5	1.0	56.3	99.8
4	—	1.0	65.0	—
5	37.4	1.35	63.0	101.75
6	35.9	1.4	60.3	97.6
7	45.1	1.0	57.3	103.4
8	36.8	1.3	65.0	103.1
9	33.7	1.0	65.3	100.0
10	34.5	0.8	59.0	94.3
11	37.8	0.8	63.0	101.6
12	36.6	0.8	63.0	100.4
Means	38.1	1.0	61.3	100.4

The proportion of calcium retained in the cheese is quite consistent in these twelve trials. A comparison of these values with the cheesemaking record (Table 2) fails to indicate any close correlation between calcium losses and high acidities or "fast working" curds. It may be assumed therefore, that the minor variations which commonly occur in cheddar cheesemaking technique from day to day or from factory to factory, are unlikely to alter the efficiency with which this element is retained in the cheese. No evidence of seasonal variation in retentions of calcium can be noted.

Retention of Phosphorus

Values on phosphorus retention have been calculated in a manner similar to those for calcium and are presented in Table 4.

TABLE 4.—LOSSES AND RETENTIONS OF PHOSPHORUS IN CHEDDAR CHEESE-MAKING

Lot No.	First whey	Press whey	Cheese	Total
	%	%	%	%
1	53.6	0.62	52.5	106.7
2	48.1	0.7	51.0	99.8
3	47.5	0.7	49.0	97.2
4	43.5	0.7	54.8	99.0
5	45.2	0.9	55.0	101.1
6	44.8	1.0	53.3	99.1
7	48.5	0.5	50.0	99.0
8	46.0	1.0	55.6	102.6
9	40.0	0.6	57.0	97.6
10	44.0	0.7	50.0	94.7
11	44.9	0.6	51.7	97.2
12	46.8	0.6	57.8	105.2
Means	46.1	0.72	53.1	99.9

These values indicate that the proportion of phosphorus lost is greater than that for calcium. Coefficients of variation have not been calculated but they appear to be about equal for both sets of values. If a comparison of the above values is made with those of Table 3, it will be noted that in most instances, where losses of calcium are above the average, those of phosphorus are also. The same factors may, therefore, be assumed to affect the retention of both these minerals.

Retention of Riboflavin

Milk is an abundant source of riboflavin but the extent to which this vitamin is retained in other dairy products has not been fully established. The higher the rate of retention the more valuable will be the product. In Table 5 will be found the proportions of this vitamin accounted for either in the first whey, press whey or in cheese one day old. Once again these values are presented as percentages of the amount originally present in the milk.

TABLE 5.—LOSSES AND RETENTIONS OF RIBOFLAVIN IN CHEDDAR CHEESE-MAKING

Lot No.	First whey	Press whey	Cheese (1 day old)	Total
	%	%	%	%
1	65.0	0.25	24.0	89.2
2	59.5	0.3	18.0	77.8
3	57.2	0.45	20.0	77.6
4	59.0	0.4	20.6	80.0
5	68.0	0.46	25.0	93.5
6	51.5	0.6	25.5	77.6
7	66.0	0.3	20.5	86.8
8	70.0	0.5	25.2	95.7
9	76.0	0.5	32.0	108.5
10	76.0	0.45	23.6	100.0
11	80.0	0.5	22.2	102.7
12	57.0	0.5	23.0	80.5
Means	65.4	0.43	23.3	89.13

In view of the fact that riboflavin is a water-soluble substance, an average rate of retention of 23.3% is better than might be anticipated. The range of values here is much greater than is the case for either of the minerals and there is no evidence to indicate that losses of minerals and vitamins might be correlated. Low retention rates may be due to higher than average losses in the whey or to destruction of this nutrient during manufacture. The possibility of finding ways of retaining a higher proportion of this substance in the cheese is therefore, something of a challenge. Some of the methods by which this might be achieved are dealt with in the discussion.

THE STABILITY OF RIBOFLAVIN DURING RIPENING

The study of changes in riboflavin content during ripening is complicated by the fact that the moisture content of cheese usually varies slightly from vat to vat and also that "shrinkage," due to evaporation of moisture from the cheese, goes on throughout the ripening period. In these experiments shrinkage was accelerated as a result of the fact that the cheese were small. Table 11 in the Appendix shows the values for fat and

total solids content for cheese ripened at the two temperatures. Figure 1, which is a graph of the mean values for total solids at the two ripening temperatures should be of special interest to everyone concerned with

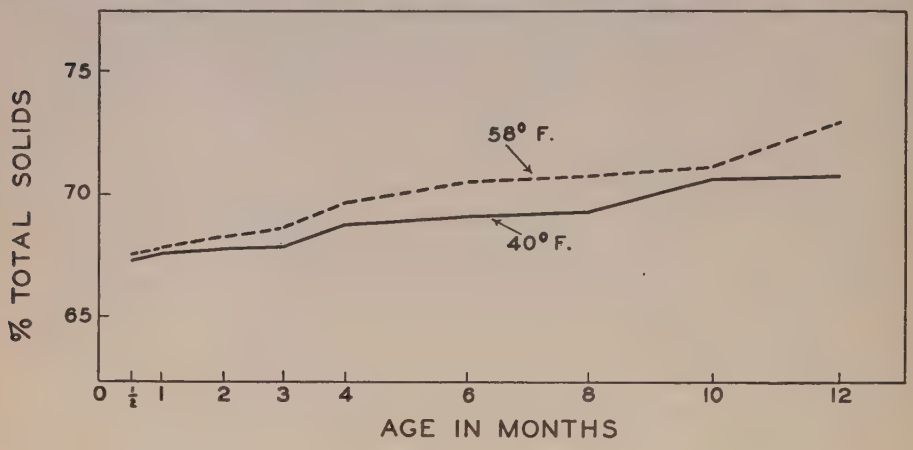

FIGURE 1. Increase in total solids content of cheese as a result of evaporation during ripening.

cheese manufacture since it indicates that shrinkage is a problem throughout the whole of the ripening period. In the case of these cheese the rate of moisture loss is accentuated by the fact that the surface area was large in proportion to the weight of the cheese, and also by the fact that the relative humidity of the storages was not always maintained at a very high level.

In order to correct for this shrinkage error which tends to distort the riboflavin results, these values have been calculated to a 35% moisture content basis. The minimum, maximum and mean values throughout the ripening period at the two temperatures used, are presented in Table 6 and in graph form in Figure 2.

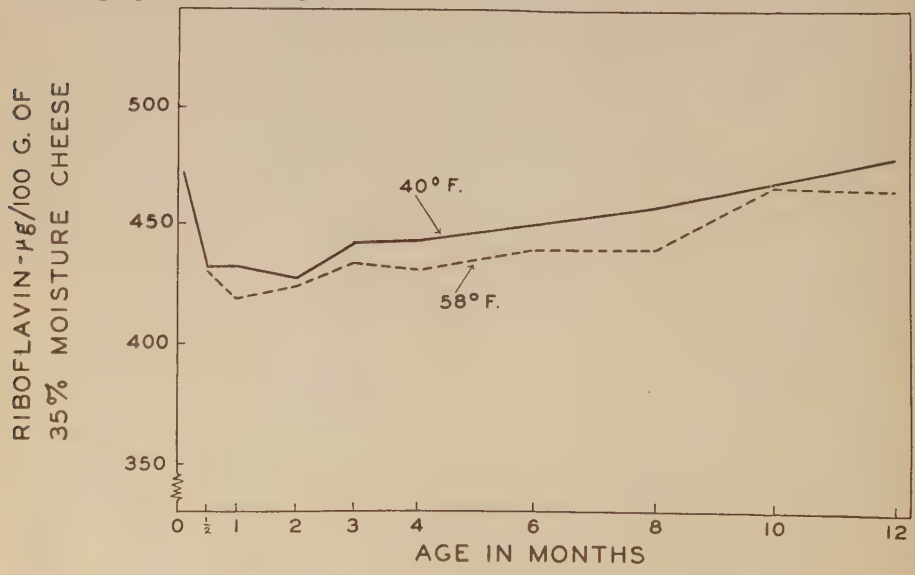

FIGURE 2. Variations in riboflavin content of cheese during ripening. Average of 12 lots.

TABLE 6.—STABILITY OF RIBOFLAVIN DURING RIPENING*

Age	Ripening temperature—40° F.									
	1	14 da.	1	2	3	4	6	8	10	12 mo.
Min.	390	374	367	364	380	413	408	420	444	429
Max.	585	483	468	470	485	492	487	496	530	540
Mean	468	434	434	428	444	444	451	457	467	477
	Ripening temperature—58° F.									
Min.	390	393	332	365	391	391	428	403	437	432
Max.	585	474	463	461	479	468	470	459	513	515
Mean	468	434	420	424	435	431	442	440	464	465

* The results presented are the minimum, maximum and mean values on 12 lots in micrograms per 100 g. of 35% moisture cheese.

From an examination of the data in Table 6, it is quite evident that the riboflavin content of cheese is not adversely affected, even after extended periods of ripening at relatively high temperatures. The range of values is narrow and it may therefore be concluded that any sample of cheese which has been manufactured under similar conditions could be expected to be an equally good source of this vitamin.

It will be noted that from the beginning of ripening until the second month, a diminution in riboflavin values takes place, after which a gradual increase occurs until at the end of the 12-month period values slightly in excess of the original ones prevail. This fluctuation is more pronounced at the higher ripening temperature. The factors which produce these variations are not known but some of the probable causes are discussed below.

THE EFFECT OF DIFFERENT SOIL TYPES ON CALCIUM, PHOSPHORUS AND RIBOFLAVIN CONTENT OF MILK, AND THE CHEESE MANUFACTURED FROM IT

In order to ascertain whether the results of the main experiment were in accord with results which might be secured at commercial factories, it was decided to obtain samples of milk and cheese at factories in different parts of the province, and carry out similar analyses to those reported above. This also afforded an opportunity to select areas which were representative of different soil types and thus determine whether soil might be a factor in influencing the mineral relationships of the milk. The localities listed below were suggested by Prof. F. F. Morwick of the O.A.C. Soils Division as being good examples of the soil types desired. Arrangements were therefore made to visit these plants and obtain samples. Visits were made during June and again during September of 1942.

At each factory a vat of milk was selected and samples of the milk plus starter were taken just before rennetting. Whey samples were secured at the running stage. When the curds were ready for pressing, two 10-pound hoops were filled from the vat and pressed into cheese. The milk

and whey samples were chilled and dispatched to the laboratories while samples of cheese were forwarded on the following day. The two cheeses were then expressed to Guelph where they were held for six months at 40° F. Samples of these were assayed for riboflavin at one and 14 days and at 6 months. The results of the study are presented in Table 7.

TABLE 7.—EFFECT OF LOCALITY ON CALCIUM, PHOSPHORUS AND RIBOFLAVIN CONTENT OF MILK AND THE CHEESE MANUFACTURED FROM IT

Factory	County	Soil characteristics	Date	Fat	Milk			
					T.S.	Ca	P	Ribo.
				%	%	(mg. %)		(μg. per 100 g.)
1223 Homestead	Oxford	P deficient; fair lime	June	3.09	11.38	—	—	205
			Sept.	3.08	11.28	111	70	196
239 Selwyn	Peterborough	High lime; fair total P but low available P	June	—	—	125	95	199
			Sept.	3.45	12.01	123	82	192
943 Marvelville	Carleton	Suitable Ca/P balance; good fertility	June	3.21	11.53	118	86	204
			Sept.	3.11	11.53	114	76	212
632 Milbrook	Russell	Acid soil area	June	3.51	12.32	117	84	187
			Sept.	3.52	12.07	114	70	207

Factory	Date	Cheese				
		Ca	P	Riboflavin (μg. per 100 g. of 35% moisture cheese)		
		(mg. %)		1 da.	14 da.	6 mo.
1223	June	—	—	—	439	527
	Sept.	676	440	430	482	484
239	June	820	508	408	392	—
	Sept.	616	432	446	452	462
943	June	640	424	418	393	520
	Sept.	624	414	466	466	495
632	June	724	424	473	395	452
	Sept.	632	404	470	436	482

These results are of much the same order as those found in the main experiment. Because of their confirmatory character they strengthen the evidence that minor variations in cheese making methods or in milk supplies are not likely to affect markedly the nutritive value of cheese in respect to minerals or riboflavin.

CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN CHEESE POSSESSING DEFECTIVE FLAVOURS

It was thought possible that cheese of poor flavour quality might display abnormal values for these nutrients either because of undesirable fermentations in the process or for some other cause. Through the kindness of the dairy produce graders of the Dominion Department of Agricul-

ture, a number of second and third grade samples were secured. An equal number of first grade samples were also sent along to serve as controls. The results are presented in Table 8. Except for the one sample of "not clean" cheese, the results are averages of several samples.

TABLE 8.—CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN FLAVOUR DEFECTIVE CHEESE COMPARED WITH THOSE OF FIRST GRADE FLAVOUR

Flavour	No. of samples	Ca	P	Riboflavin μg./100 g.
		mg. %	mg. %	
Off	3	527	467	448
Rancid	4	555	414	464
Fruity	4	608	428	451
Not clean	1	476	412	472
First grade	12	561	420	462

In the case of the mineral results, the individual values from which these averages were calculated displayed a greater variation than did the results in the controlled experiment. This was true of the results from both defective and first grade samples. It will be noted from the averages, however, that, except for the one "not clean" sample, these values do not vary markedly from the first grade controls. With regard to riboflavin, it is apparent that the factors causing defective flavour do not affect adversely the retention of this vitamin.

DISCUSSION

The results of the cheese analyses for mineral content reported in this paper, are far from being in agreement with those of McCammon, Caulfield and Kramer (9), who reported retentions of 80% for calcium and 38% for phosphorus. In the present study the fact that it has been possible to account for almost all the minerals, either in the whey or cheese, increases our confidence in the methods of analysis which were used. The retention of phosphorus would appear to be particularly low in the above-mentioned study in view of the fact that much of the phosphorus of milk is present as a constituent of casein. On the other hand the values here reported are in close agreement with those of Mattick (11).

Confirmatory evidence is furnished in this study that the riboflavin content of milk is not affected by season or by shifts from pasture to stable feeding or *vice versa*. This is now the accepted view (5, 6), although the claim has been made by others (1, 17,) that the riboflavin content of milk can be increased from 50 to 75% by increasing this factor in the ration.

Houston and Kon (4) have commented on the fact that retentions of riboflavin in English cheeses are about five times greater than can be accounted for on the basis of this vitamin's water solubility. This may result from the fact that a part of the riboflavin in milk is known to be present as riboflavin-protein complexes. Kuhn and Kaltschmitt (8) note that 10% of this vitamin in milk is in an undialysable form. Sharp (13) has stated that this flavoprotein (probably Schardinger enzyme or xanthine oxidase) is closely adsorbed on the fat globule. He (with Hand) has also stated (14) that the proportion of riboflavin adsorbed can be maintained at a maximum by methods which involved temperature changes.

One feature of the riboflavin picture which should receive further study is the seasonal variation in the unaccountable loss of riboflavin during manufacture. Table 5 above contains the percentages of riboflavin either lost in the wheys or recovered in the cheese in the twelve trials. The totals of these values have been arranged in two groups in Table 9.

TABLE 9.—LOSSES OF RIBOFLAVIN DURING MANUFACTURE AT DIFFERENT SEASONS OF THE YEAR

Total recovery of riboflavin in wheys and cheese as percentage of original in milk			
Winter months		Summer months	
	%		%
Nov.	86.8	May	89.2
Dec.	95.7	June	77.8
Jan.	108.5	July	77.6
Feb.	100.0	Aug.	80.0
Mar.	102.7	Sept.	93.5
Apr.	80.5	Oct.	77.6
Mean	95.7		82.6
Loss not accounted for	4.3		17.4

It is suggested that the loss may be due to the destruction of this vitamin by light, the much higher loss during the summer months being the result of greater light intensity during that period. This explanation seems plausible since the laboratory in which the cheese were made is a well-lighted one and is not shaded by trees during the summer. It is planned to study the possible effect of light in a later project.

SUMMARY

A study has been made of the losses and retentions of calcium, phosphorus, and riboflavin in Canadian cheddar cheese made from raw milk. The effect of ripening the cheese for 12 months on the stability of riboflavin was also studied.

Of the original calcium present in the milk, about 61% was retained in the cheese. Of the original phosphorus, about 53% was accounted for in the cheese. These values were subject to small variations but did not vary with season, nor could they be correlated with minor changes in cheesemaking methods. The losses were almost entirely accounted for in the whey removed during running and stirring.

About 23% of the riboflavin originally present in the milk was retained in the cheese. The variations in this case were of somewhat greater proportions. Riboflavin appeared to be stable throughout a ripening period of 12 months both at temperatures of 40° and 58° F. There was an apparent diminution during the first two months but this was followed by an equal increase during the final months of ripening.

A small number of samples of milk and cheese were secured from factories in the province which represented varying soil types. Soil does not appear to be a significant factor affecting mineral retention in cheese. Riboflavin values were similar to those in the main experiment.

The calcium, phosphorus and riboflavin contents of cheese of defective flavour appear to be essentially the same as those of first grade cheese.

ACKNOWLEDGMENTS

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TABLE 10.—Ca, P, AND RIBOFLAVIN IN MILK, FIRST WHEY, PRESS WHEY AND ONE-DAY OLD CHEESE

Lot G No.	Milk					First whey					
	Fat	T.S.	Ca	P	Ribo.	Yield	Fat	T.S.	Ca	P	Ribo.
	*	*	*	**	***	*	*	*	**	**	***
1	4.26	13.08	134.0	90	194	88.0	0.39	7.05	55.3	55	144
2	3.73	12.40	123.5	85	207	92.2	0.32	6.92	58.0	44	132
3	3.78	12.51	125.5	88	194	87.9	0.36	6.93	60.8	47.5	126
4	4.66	12.54	120.0	90	207	87.2	0.37	6.97	69.0	45	180
5	3.95	12.83	118.5	85	202	85.8	0.35	7.06	50.8	44	158
6	4.00	12.90	128.5	87	193	87.4	0.39	6.77	52.0	43.8	112
7	3.83	12.57	105.5	81	218	86.7	0.41	7.00	54.5	45	165
8	3.96	12.93	124.5	89	212	90.0	0.38	6.98	49.5	44.5	160
9	3.81	12.51	119.0	82	180	86.3	0.38	7.00	46.8	38	159
10	3.95	12.73	134.0	87	198	85.3	0.45	7.09	54.3	45	177
11	3.39	12.03	125.0	83	199	88.3	0.34	6.89	53.5	42	180
12	3.97	12.66	121.5	80	204	86.8	0.36	6.99	51.5	43	133

Lot No.	Press whey						Cheese (1 day old)					
	Yield	Fat	T.S.	Ca	P	Ribo.	Yield	Fat	T.S.	Ca	P	Ribo.
	*	*	*	**	**	***	*	*	*	**	**	***
1	0.42	1.20	15.7	215	132	126	10.28	37.4	67.3	782	462	452
2	0.44	2.47	20.0	248	130	137	9.37	35.1	66.1	756	460	396
3	0.54	4.45	21.1	225	118	161	9.08	34.8	65.8	728	444	401
4	0.52	2.72	18.8	225	126	159	9.74	33.2	65.3	800	508	440
5	0.53	1.50	16.7	301	146	176	9.98	35.5	66.2	736	460	497
6	0.56	3.39	19.1	297	148	188	10.36	34.5	66.0	740	440	468
7	0.38	4.78	19.5	258	139	184	9.45	35.2	66.5	632	424	468
8	0.60	1.51	16.1	273	148	198	9.88	35.85	67.1	824	500	538
9	0.51	2.31	18.0	213	104	192	9.62	35.3	66.7	808	480	600
10	0.47	1.34	19.6	217	123	190	9.54	35.3	65.9	828	452	490
11	0.53	1.98	21.2	190	97	194	8.93	33.9	65.8	876	480	497
12	0.59	1.43	17.5	161	87	175	9.87	36.6	66.9	776	468	475

* In percent. ** In mg. %. *** In micrograms per 100 g.

TABLE 11.—CHANGES IN FAT AND TOTAL SOLIDS CONTENT OF CHEESE DURING RIPENING

Values in per cent.

No.	40° F.									
	Age—mo.	½	1	2	3	4	6	8	10	12
1	Fat	38.2	38.3	38.2	38.5	38.7	39.9	39.9	39.5	39.2
	T.S.	69.1	68.8	68.6	68.8	70.2	71.4	72.1	72.2	71.2
2	Fat	35.6	36.2	35.8	36.3	36.5	36.6	36.8	36.9	37.3
	T.S.	66.3	66.9	66.8	67.8	68.1	68.2	69.1	69.2	69.5
3	Fat	35.2	35.1	35.6	35.9	35.8	36.3	35.7	36.0	36.1
	T.S.	65.8	66.2	69.6	67.6	67.8	69.6	69.1	68.5	68.8
4	Fat	33.9	35.5	34.4	34.6	34.5	35.8	36.3	36.2	35.6
	T.S.	65.9	66.7	66.4	66.7	66.8	69.7	71.1	70.8	69.6
5	Fat	35.7	36.2	36.4	36.6	37.4	36.9	36.5	37.1	37.2
	T.S.	66.8	67.2	67.6	68.4	69.9	69.4	68.3	70.4	70.1
6	Fat	35.4	35.4	35.6	35.6	36.2	36.2	35.6	35.9	36.6
	T.S.	66.4	66.8	67.5	67.9	69.0	68.8	67.8	68.6	70.0
7	Fat	36.1	36.0	36.1	36.3	36.8	36.9	36.9	—	37.0
	T.S.	68.2	67.3	68.0	68.2	70.0	70.0	69.9	—	69.6
8	Fat	36.5	36.4	36.8	36.4	37.0	36.5	37.3	39.0	39.9
	T.S.	68.6	68.5	69.0	68.9	69.2	69.2	70.2	73.2	72.5
9	Fat	36.0	36.4	36.2	36.3	36.2	36.3	36.4	36.6	38.4
	T.S.	68.2	69.0	68.5	68.6	68.5	68.4	69.1	69.3	73.1
10	Fat	35.7	36.3	36.2	36.4	36.5	36.4	36.5	38.4	38.2
	T.S.	67.0	67.7	67.2	67.3	68.0	68.4	68.0	72.3	70.7
11	Fat	34.1	34.5	34.1	34.2	34.4	34.2	34.5	39.0	36.2
	T.S.	66.4	66.6	66.1	66.4	67.0	66.6	66.5	72.8	72.4
12	Fat	37.2	37.5	37.4	37.5	37.9	38.3	38.3	38.2	38.6
	T.S.	67.9	68.7	68.6	67.6	69.2	69.7	69.7	69.8	71.2

No.	58° F.									
	Age—mo.	½	1	2	3	4	6	8	10	12
1	Fat	—	38.6	38.6	38.8	39.5	39.7	39.6	39.5	41.1
	T.S.	—	69.5	69.3	69.7	71.6	71.7	71.7	72.6	75.6
2	Fat	35.7	36.2	36.4	37.5	36.9	37.1	38.9	38.1	37.6
	T.S.	66.6	67.2	67.9	69.7	69.1	69.5	73.6	71.5	70.9
3	Fat	35.1	35.5	35.8	36.2	35.8	36.9	36.0	37.0	36.9
	T.S.	66.3	66.7	67.9	68.2	67.4	70.2	69.1	70.6	70.9
4	Fat	33.9	34.3	35.6	34.7	35.4	36.4	35.4	36.0	35.7
	T.S.	66.1	66.6	67.0	67.4	68.8	71.9	69.5	71.3	71.3
5	Fat	35.9	36.4	36.7	36.7	38.1	37.9	37.5	37.3	37.4
	T.S.	67.4	67.7	68.3	69.0	72.2	71.6	70.4	71.0	70.9
6	Fat	35.7	35.4	35.6	36.9	36.3	36.2	37.3	36.5	37.1
	T.S.	67.2	67.4	68.9	70.1	69.6†	69.3	72.0	70.2	71.6
7	Fat	35.8	35.9	36.2	36.7	36.4	37.0	37.9	—	39.3
	T.S.	68.2	68.1	68.3	69.3	69.8*	69.8	71.9	—	74.9
8	Fat	36.8	36.4	36.8	37.1	36.8	38.8	38.3	38.2	38.5
	T.S.	69.1	68.4	69.3	70.0	70.4	73.2	72.8	72.3	73.0
9	Fat	36.0	36.6	36.4	36.5	36.6	36.7	37.0	37.2	39.2
	T.S.	68.4	69.1	68.8	68.9	69.3	70.2	70.6	70.8	75.1
10	Fat	36.1	36.7	36.1	35.9	37.8	37.1	36.9	38.8	39.3
	T.S.	67.8	68.6	67.8	67.3	71.3	69.6	68.9	73.3	73.7
11	Fat	34.6	34.5	34.0	34.1	34.6	34.4	34.8	36.6	37.4
	T.S.	66.8	66.6	66.4	66.5	67.4	67.4	67.4	67.8	73.0
12	Fat	37.1	37.1	37.6	37.7	37.7	38.7	38.6	39.2	40.8
	T.S.	68.4	69.1	69.3	67.7	69.4	71.3	71.2	71.4	74.7

TABLE 12.—CHANGES IN RIBOFLAVIN CONTENT OF CHEESE DURING RIPENING

Micrograms per 100 g. of cheese

Lot No.	40° F.								
	Age—mo. ½	1	2	3	4	6	8	10	12
1	397	388	386	401	448	449	477	497	510
2	389	393	393	456	444	468	493	472	513
3	417	420	458	424	430	478	489	478	563
4	471	451	456	478	478	498	460	506	542
5	—	434	443	477	489	490	495	491	486
6	436	471	470	487	483	472	518	506	561
7	460	466	440	480	485	493	473	—	577
8	497	490	477	480	468	519	510	561	551
9	482	470	449	436	468	458	490	543	482
10	497	486	480	490	514	461	448	589	498
11	470	460	478	495	450	480	488	456	496
12	430	475	436	451	468	494	490	482	509
	58° F.								
1	391	318	361	377	432	480	469	—	509
2	403	352	381	447	448	459	482	486	509
3	413	399	458	431	417	466	485	481	562
4	460	435	461	469	471	483	430	509	546
5	—	396	429	468	471	492	491	490	494
6	435	469	461	487	475	464	509	519	535
7	441	473	445	478	475	490	474	—	571
8	492	487	475	469	467	509	517	545	545
9	467	469	451	436	445	470	476	530	500
10	495	489	479	479	513	468	445	580	493
11	466	462	471	490	454	487	476	462	494
12	427	474	438	445	485	484	502	480	507

THE RETENTION OF NUTRIENTS IN CHEESE MAKING

II. THE EFFECT OF PASTEURIZATION OF THE MILK UPON THE RETENTION OF CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN CHEDDAR CHEESE[1]

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In a previous publication (8) the efficiency of the cheddar cheese manufacturing process was reported on with respect to the retention of calcium, phosphorus and riboflavin. In that study raw milk was used exclusively. In view of the fact that pasteurization of cheese factory milk supplies is practised in some countries and is advocated by many public health authorities, it seemed advisable to determine whether pasteurization would affect the retention of these nutrients. A study has therefore been carried out comparing raw milk with milks pasteurized by the conventional holder method and by the high-temperature short-time method with regard to the effect of these heat-treatments upon nutrient retentions. The experiment was so designed that the effect of these methods of pasteurization could be compared with each other and with a raw milk control. Trials were run at intervals of two months during the period from May, 1942 to April, 1943. As in the previous study, cheeses from each vat were ripened at two temperatures, 40° F. and 58° F. Ripening was continued for only six months in this case, however.

HISTORICAL

It is the intention of the authors to report on the effect of these two methods of pasteurization upon the yield and quality of cheese in a later paper. For that reason much of the literature relating to the effect of pasteurization upon cheddar cheese will not be reviewed here.

The effect of two different methods of pasteurization of the milk upon the mineral content of cheddar cheese has been investigated by Moir (12). Pasteurization yielded cheese of reduced calcium and phosphorus content and altered Ca./P ratio. In these studies, however, abnormal acidities during manufacture appear to have influenced mineral retentions. In their studies on pasteurized milk cheddar cheese, Dolby, McDowall and McDowell (2) secured mineral retentions similar to those reported by us (8) for raw milk cheddar cheese.

Holland and Dahlberg (4) have studied the effect of time and temperature upon some of the properties of milk. Their observations on the effect of heat treatment upon rennet coagulability and changes in the calcium

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phosphate are of interest here. Their data show that with holding periods of 10 minutes or more, the range between 160° and 180° F. is the critical one. They were unable to discern any change in the relative proportions of $CaHPO_4$ and $Ca_3(PO_4)_2$ brought about by heating at normal pasteurizing time temperature combinations or at temperatures up to 165° F. for periods up to 5 minutes. Mattick and Hallet (11) found no reduction in the amount of diffusible phosphorus at temperatures below 175° F. with a 30-minute holding period. They did observe, however, that with this holding time, temperatures above 125° F. produced a marked reduction in the diffusibility of the calcium salts.

As a result of their investigations Magee and Harvey (10) suggest that calcium salts in milk are changed from a soluble to a colloidal form by heat.

Holmes *et al* (5) and Houston, Kon and Thompson (7) have studied the effect of pasteurization of milk upon riboflavin stability and both agree that losses are negligible. The riboflavin in milk was found to be thermostable even at sterilizing temperatures by Henry and Kon (3) and by Houston, Kon and Thompson (7).

EXPERIMENTAL

This study was carried out by using split batches of milk, six experiments being run. In order that they might not be influenced by seasonal conditions and that the analyses could be staggered, an interval of two months was allowed between each experiment.

On each of these occasions, approximately 1800 pounds of milk was secured from the College herd and after being thoroughly mixed was divided into three equal lots. The first of these served as a raw control and was manufactured into cheddar cheese following the method previously mentioned (8). The second lot was pasteurized by the holder method at 143° F. for 30 minutes after which it was cooled to between 50-70° F. in the cooling section of an A.P.V. regenerative pasteurizer. An 80-gallon stainless steel Cherry-Burrell vat was employed for heating and holding this milk, care being taken to avoid excessively fast heating or overheating in this operation.

The third lot of milk was pasteurized by passing it through a 250-gallon per-hour A.P.V. regenerative pasteurizer, heating to 161° F. and holding for 16 seconds. Here again the milk was cooled to between 50-70° F. The cheese making process was begun with both types of pasteurized milk immediately after pasteurization. Samples of milk plus starter were taken before rennetting from each of the vats. While slight modifications have to be made in the method of manufacture when pasteurized milk is used, the method followed in this study was very similar to that for the parallel vats of raw milk cheese.

Samples of "first" whey and "press" whey were again taken, all the wheys being collected separately, and in this case weighed. The same procedure was also followed in taking the cheese samples except that the number was reduced and the ripening period was restricted to six months. The schedules of samplings for each series of vats is given in Table 1.

TABLE 1.—SCHEDULE FOR SAMPLING AND ANALYSES OF MILK, WHEY AND CHEESE

Analysis	Milk			First whey			Press whey		
	Raw	Hold	H.S.	Raw	Hold	H.S.	Raw	Hold	H.S.
Fat	x			x	x	x	x	x	x
T.S.	x			x	x	x	x	x	x
Ca.	x	x	x	x	x	x	x	x	x
P.	x	x	x	x	x	x	x	x	x
Ribo.	x	x	x	x	x	x	x	x	x

Analysis	Cheese (Raw, Hold and H-S)							
	Age—1 da.		14 da.		3 mo.		6 mo.	
	Temp.—40	58	40	58	40	58	40	58
Fat	x		x		x		x	
T.S.	x		x		x		x	
Ca.	x							
P.	x							
Ribo.	x	x	x	x	x	x	x	x

The methods of analysis employed in the project previously reported (8) were again used in this study.

RESULTS

In view of the possibility of certain variations in manufacturing technique exerting some effect upon the results obtained, especially on the retention of minerals, such values as the rates of starter, rennetting acidities, etc. were carefully recorded. These are shown in Table 2.

TABLE 2.—DETAILS OF THE CHEESE MAKING PROCESS

Series	Date	Treatment	Starter	Milk ripening period	Setting acidity	Set to run	Running acidity	Run to salt	Rate of salt lb./1000 lb. milk
			%	min.	%	min.	%	min.	milk
P_1	28/5/42	Raw	1.0	75	0.20	180	0.180	185	2.5
		Hold	1.0	91	0.19	194	0.165	180	2.5
		H-S	1.0	89	0.195	186	1.165	190	2.5
P_2	28/7	Raw	1.0	72	0.18	205	0.175	120	2.25
		Hold	1.0	70	0.17	190	0.175	185	2.25
		H-S	1.0	70	0.18	210	0.18	195	2.25
P_3	28/9	Raw	1.2	59	0.185	191	0.18	205	2.37
		Hold	1.2	45	0.175	180	0.17	180	2.37
		H-S	1.2	61	0.175	170	0.17	195	2.37
P_4	25/11	Raw	1.6	90	0.18	160	0.185	175	2.25
		Hold	1.6	30	0.18	180	0.175	190	2.25
		H-S	1.6	55	0.17	165	0.17	180	2.25
P_5	25/1/43	Raw	1.2	70	0.185	215	0.19	—	2.25
		Hold	1.2	70	0.165	200	0.165	—	2.25
		H-S	1.2	70	0.175	190	0.165	—	2.25
P_6	25/3	Raw	1.0	46	0.18	226	0.185	180	2.25
		Hold	1.0	42	0.175	168	0.165	170	2.25
		H-S	1.0	49	0.18	171	1.165	180	2.25

Rennet extract was added at rate 3 fl. oz. per 1000 lb. of milk.

It will be noted that a lower running acidity was usually employed for the pasteurized milk vats. This is commonly the practice since it is possible to carry out the manufacturing process at lower acidity values. In addition, the titratable acidity of the milk is reduced slightly in pasteurization, particularly when the holder method is used.

Retention of Nutrients

Tables 9 and 10 in the Appendix show the data for fat, total solids, yield, calcium, phosphorus and riboflavin for each lot of milk plus starter, "first" whey, "press" whey and cheese. Table 11 gives the riboflavin values on the cheese throughout the ripening period and at the two temperatures.

Assessing the efficiency with which these nutrients are retained in the cheese has been done by expressing the proportion of the nutrient retained as a percentage of the amount originally present in the milk.

Calcium

The percentage values for the retention of calcium are presented below in Table 3 and in Figure 1.

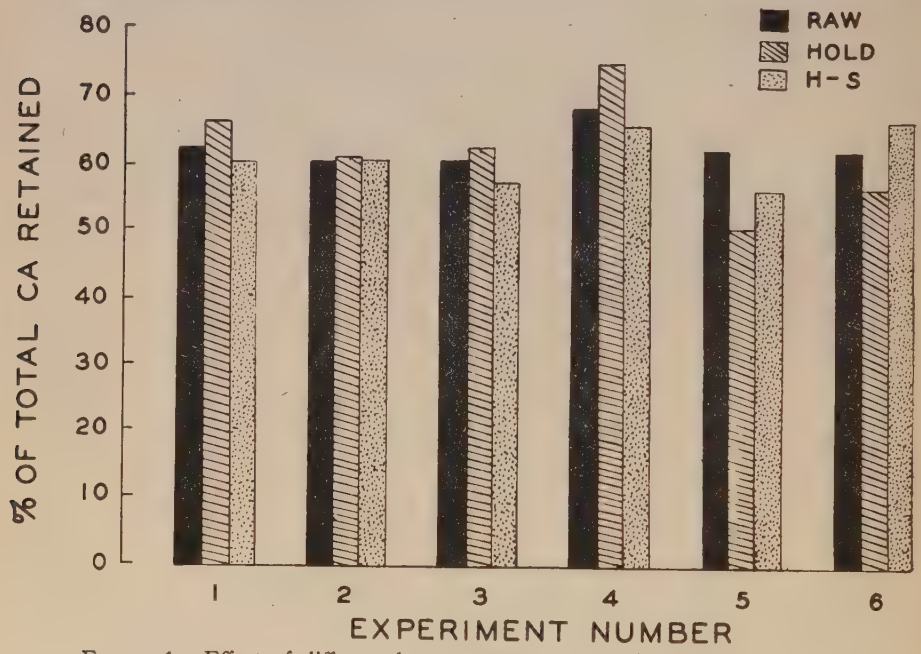

FIGURE 1. Effect of different heat treatments upon the efficiency of retention of calcium in cheese.

TABLE 3.—PERCENTAGE OF TOTAL CALCIUM RETAINED IN CHEESE

Series	Treatment of milk		
	Raw	Holder	High-Short
P_1	62.70	66.80	60.53
P_2	60.64	61.38	61.19
P_3	61.12	63.02	57.80
P_4	68.44	75.81	66.28
P_5	62.38	50.91	56.70
P_6	62.55	57.27	67.21
Mean	62.97	62.53	61.62

It is quite apparent from these results that any difference produced by heat treatment of the milk upon the retention of calcium in the cheese is of no great significance. In general, the retention values are much more uniform for the raw milk curds than for those made from pasteurized milk.

A careful study of the values for calcium losses in the wheys as presented in the Appendix, will reveal that the sum of the calcium present in the whey plus that retained in the cheese is, in some instances, greater than the total amount originally present in the milk. In some instances also, the values obtained for the pasteurized milks are greater than for the corresponding raw milks. Errors of this character are not apparent in the case of fat, total solids, phosphorus or riboflavin. It must therefore be concluded that the method employed for the determination of calcium was less accurate than it should have been.

Phosphorus

Results for the retention of phosphorus have been compiled in a similar manner and are presented in Table 4 and Figure 2.

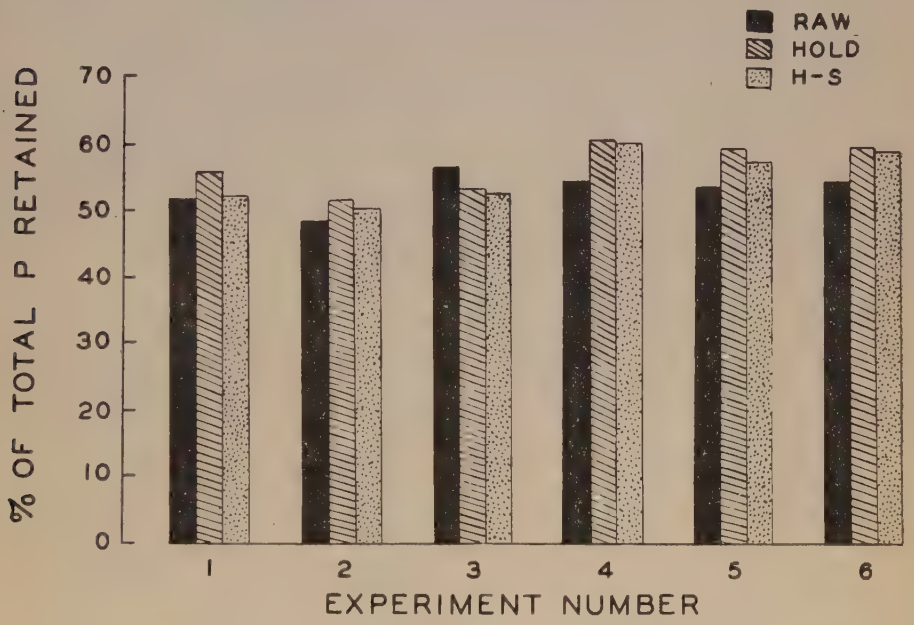

FIGURE 2. Effect of different heat treatments upon the efficiency of retention of phosphorus in cheese.

TABLE 4.—PERCENTAGE OF TOTAL PHOSPHORUS RETAINED IN CHEESE

Series	Treatment of milk		
	Raw	Holder	High-Short
P_1	51.90	55.90	52.32
P_2	48.35	51.81	50.54
P_3	56.16	53.61	52.63
P_4	54.31	60.88	60.18
P_5	53.71	59.66	57.50
P_6	54.40	59.94	59.57
Means	53.14	56.97	55.46

With the exception of one series, P_3, the pasteurized milk cheese display a consistently higher rate of phosphorus retention. In view of this consistency it seems apparent that this result is a significant one.

Riboflavin

Special interest is attached to the retention of riboflavin in cheese making and also to any influence which pasteurization may have on these values.

The effect of pasteurization upon the destruction of this vitamin has been studied on several occasions. Reference to Table 9 will reveal the extent to which this vitamin was affected by heating in each trial. These results are summarized in Table 5.

TABLE 5.—EFFECT OF PASTEURIZATION ON THE DESTRUCTION OF RIBOFLAVIN IN MILK

(μg./100 g.)

	Treatment of milk		
	Raw	Holder	High-Short
Means of 6 trials	201.8	197.3	198.8

The differences between these means are very small and are typical of the results that have been reported by Holmes *et al.* (5). All three values, however, appear to be higher than those appearing in a recent compilation by Booher, Hartzler and Hewston (1).

The losses and retentions of riboflavin are set forth in Table 9. The efficiency with which the riboflavin was carried over into the one-day-old cheese is more readily understood when calculated as percentages of that originally present in the milk. These percentages are given in Table 6.

TABLE 6.—PERCENTAGE OF THE TOTAL RIBOFLAVIN RETAINED IN CHEESE

Series	Treatment of milk		
	Raw	Holder	High-Short
P_1	21.60	20.29	22.38
P_2	20.06	19.52	18.35
P_3	24.62	24.81	24.74
P_4	22.60	21.53	22.48
P_5	33.04	22.14	22.32
P_6	22.55	25.97	24.80
Means	24.08	22.38	22.51

Attention is directed to the value 33.04% as given for P_5 raw milk. Reference to Table 9 in the Appendix shows that this sample of cheese at one day contained 706 μg./100 g. of riboflavin as compared with 484 and 478 in the holder and high-short samples. This assay on the raw-milk cheese was repeated six times but an abnormally high value was always

obtained. At later stages of ripening this cheese displayed values ranging from 422 to 484 μg./100 g. It would seem logical therefore, that this result is an aberrant one and should not be included in the calculation of this mean. There are a number of factors which might have produced this erroneous result, chief of which would be that the cheese sample became contaminated with riboflavin producing micro-organisms (13).

If the value in question be deleted for purposes of calculating the mean, the remaining five values yield a mean of 22.28%. If this deletion is justifiable, one may conclude that the retention of riboflavin is not affected by the heat treatment which the milk receives.

Stability of Riboflavin During the Ripening Period

In conformity with the practice of Booher, Hartzler and Hewston (1), riboflavin values were calculated in micrograms per 100 grams of food. As was found to be the case in our previous study, however, variations in total solids content from one sample to another and even in the same lot of cheese at different stages of ripening, are likely to be considerable. The shrinkage which took place in the cheese ripened at 40° F. is illustrated in Table 7 and Figure 3.

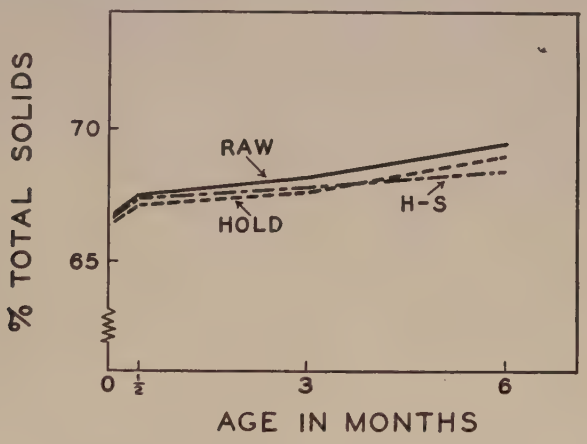

FIGURE 3. Increase in the total solids content of cheese during ripening.

TABLE 7.—AVERAGE TOTAL SOLIDS CONTENT OF CHEESE SAMPLES AT INTERVALS DURING RIPENING AT 40° F.

Age of cheese	Treatment of milk		
	Raw	Holder	High-Short
1 day	66.65	66.30	66.67
14 days	67.63	67.29	67.51
3 months	68.24	67.88	67.95
6 months	69.49	69.02	68.84

This gradual increase in total solids content tends to distort the picture of riboflavin stability unless corrections are made for these changes. In order to avoid this error the riboflavin values have been recalculated to

a 35% moisture content basis. The individual values for riboflavin on the cheese ripened at 40° and 58° F. are given in Table 11 while the means of the corrected values for the cheese ripened at 40° F. are shown in Table 8 and Figure 4. Similar results for the cheese ripened at 58° F. could not be calculated since it was not possible to secure results for total solids on these cheese.

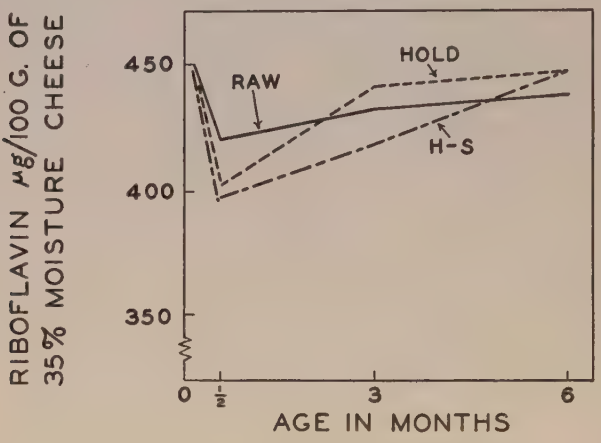

FIGURE 4. Variations in riboflavin content of cheese during ripening. Averages of six lots.

TABLE 8.—AVERAGE STABILITY OF RIBOFLAVIN DURING RIPENING. VALUES ARE EXPRESSED IN μG. OF RIBOFLAVIN PER 100 G. OF 35% MOISTURE CHEESE

Age of cheese	Treatment of milk		
	Raw	Holder	High-Short
1 day	450	440	446
14 days	419	400	396
3 months	433	441	416
6 months	438	448	447

The most evident feature of the above presentation is that, although there are apparent changes in the vitamin content of the cheese during ripening, at the end of six months the riboflavin content is essentially the same as at the beginning of the period. It is also evident that pasteurization of the milk by either process has no deleterious effect upon the vitamin content of the ripened cheese.

The diminution in vitamin content which occurred at the 14-day period is much more marked than that observed in the previous study (8). It will be noted that the fluctuation is least in the case of the raw milk cheese.

DISCUSSION

In the pasteurization of milk for cheesemaking it is important that the time-temperature combination be such that the destruction of all pathogenic

bacteria be assured. The two combinations employed in this experiment are such that they would be readily approved by most public health authorities in North America. In the event that the Canadian cheese industry were to adopt pasteurization as a modification of its present method, these or similar standards would have to be met. Any alternative methods at less effective time-temperature combinations, would not be satisfactory from the point of view of the milk sanitarian.

Approved standards of heat treatment were therefore chosen in this study. While they are not at all drastic, the equilibria involved in the chemistry of cheese making is of such a character that it is sometimes seriously affected by minor factors. This is particularly true in regard to the retention of minerals.

The suggestion of Magee and Harvey (10) that the calcium salts are partially converted to a colloidal form would suggest that pasteurization of the milk would tend to increase the retention of this element in the cheese. McDowall and Dolby (9) have interpreted the activity at the surface of a curd cube on the basis of the existence of a Donnan equilibrium. The experimental evidence in this study does not indicate, however, that either of these postulations apply in restraining the loss of calcium from the curd into the whey.

The increased retention of phosphorus as a result of pasteurization was noted above. This increase is not great but it did occur consistently in all but one experiment. It is also apparent in the lower losses which occur in the whey from the pasteurized lots. In view of the rather meagre information regarding the phosphorus compounds of milk and the effect of heat upon them, it is impossible to suggest any explanation for this. Nutritionally the extra phosphorus retained in the pasteurized milk cheese is of no great importance.

The retention values for riboflavin in the pasteurized milk cheese are of the same order as those reported in the authors' previous study on raw milk cheese (8) and agree with the findings of Houston and Kon (6). It is apparent from these results that pasteurization of the milk by either process has no adverse effect upon the retention of the vitamin. The riboflavin content of cheese is of such magnitude that this food is almost in a class by itself as a source of this vitamin. The high loss of this factor in the whey, however, presents a challenge either to find a method of utilizing it to better advantage in animal feeds or retaining more of it in the cheese. Comments on the latter possibility were made in the previous paper.

Riboflavin proved to be as stable in pasteurized milk cheese as in that made from raw milk although during the early stages of ripening a marked reduction was noted in these values. This reduction appeared more marked in both lots of pasteurized cheese than in the raw milk cheese. The evidence suggests that this recession was not an actual one and that the microbiological method of estimating riboflavin may be influenced by changes which occur in the bacterial flora of cheese and which take place concurrently with this apparent recession in riboflavin content. At the conclusion of the ripening period of six months the riboflavin values were equal to, or slightly in excess of, the original values found in the one-day-old cheese.

SUMMARY

The effect of pasteurizing milk for cheese manufacture by the holder and high-temperature short-time methods has been studied in comparison with cheese manufactured from raw milk from the point of view of the relative efficiency with which the calcium, phosphorus and riboflavin present in the milk were retained in the cheese.

The results indicate that heat treatment of the milk did not affect noticeably the retention of calcium.

Cheese made from pasteurized milk tended to retain slightly more of the phosphorus than did cheese made from raw milk.

Pasteurization by either method had no significant effect upon the retention of riboflavin when compared to the raw control.

A marked reduction in riboflavin content appeared to take place during the first 14 days of ripening. This reduction was followed by an equivalent increase with the result that the final values at the end of six months ripening were about equal to those found in the fresh cheese.

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APPENDIX

TABLE 9.—FAT, TOTAL SOLIDS, CA., P, AND RIBOFLAVIN IN MILK, FIRST WHEY, PRESS WHEY AND ONE-DAY-OLD CHEESE

Lot	Treatment	Milk					First whey					
		Fat	T.S.	Ca.	P	Ribo.	Yield	Fat	T.S.	Ca.	P	Ribo.
		%	%	mg. %	mg. %	μg/100g.	%	%	%	mg. %	mg. %	μg/100g.
P_1	Raw	4.26	13.14	129.5	96.0	193	86.9	0.37	6.91	56.2	51.5	133
	Hold					191	87.2	0.42	7.15	48.0	48.2	138
	H-S					202	86.9	0.35	7.00	47.5	49.5	137
P_2	Raw	3.39	12.20	112.5	83.0	211	88.8	0.29	6.82	48.8	44.5	139
	Hold					193	88.1	0.28	6.82	47.8	45.0	130
	H-S					199	89.0	0.27	6.79	49.5	46.0	148
P_3	Raw	4.15	13.12	123.5	85.0	196	87.9	0.40	7.21	54.0	48.0	154
	Hold					187	87.4	0.38	6.97	52.3	45.0	142
	H-S					187	89.2	0.38	6.81	53.3	45.5	147
P_4	Raw	3.76	12.38	108.0	83.0	199	86.5	0.33	6.75	50.5	45.5	148
	Hold					216	86.8	0.33	6.66	43.8	42.8	144
	H-S					206	85.3	0.27	6.59	49.3	44.0	142
P_5	Raw	3.81	12.82	123.0	84.0	206	87.7	0.39	7.02	47.3	42.0	177
	Hold					207	85.9	0.54	7.09	42.2	37.5	178
	H-S					206	87.5	0.29	6.80	45.4	41.5	175
P_6	Raw	3.72	12.54	133.5	87.0	206	86.9	0.37	6.84	50.8	43.5	150
	Hold					190	87.5	0.345	6.88	56.5	42.5	180
	H-S					193	87.5	0.33	6.86	46.5	41.0	166

Lot	Treatment	Press whey						Cheese (1-day-old)					
		Yield	Fat	T.S.	Ca.	P.	Ribo.	Yield	Fat	T.S.	Ca.	P.	Ribo.
		%	%	%	mg. %	mg. %	μg/100g.	%	%	%	mg. %	mg. %	μg/100g.
P_1	Raw	0.25	1.44	16.9	229	130	144	10.06	37.0	67.2	808	496	415
	Hold	0.56	2.54	17.0	174	100	164	10.31	36.7	66.7	852	488	376
	H-S	0.51	1.68	16.5	199	112	164	10.44	37.1	67.2	748	472	433
P_2	Raw	0.53	2.45	20.0	207	110	165	9.12	33.0	66.1	748	440	464
	Hold	0.49	6.24	22.5	220	126	169	9.33	32.8	66.1	796	472	404
	H-S	0.43	3.54	20.9	217	126	172	9.04	33.5	66.9	748	492	404
P_3	Raw	0.41	2.35	18.2	253	128	172	10.20	35.8	66.9	740	468	473
	Hold	0.41	3.25	19.4	268	136	165	10.30	35.8	66.3	764	468	450
	H-S	0.49	2.55	18.0	274	140	171	9.78	36.2	67.1	724	452	473
P_4	Raw	0.53	2.33	16.9	234	134	184	9.55	34.9	66.4	774	472	471
	Hold	0.58	2.87	19.7	230	130	194	9.75	34.6	66.4	832	512	477
	H-S	0.53	2.75	17.0	243	126	184	9.75	35.3	66.3	784	500	475
P_5	Raw	0.51	3.53	18.5	189	92	213	9.64	34.9	66.7	796	468	706
	Hold	0.32	2.61	17.5	142	76	192	9.47	33.5	65.5	672	504	484
	H-S	0.41	1.95	17.6	188	102	191	9.62	34.9	66.1	722	508	478
P_6	Raw	0.55	1.59	18.7	223	100	194	9.62	35.1	66.7	868	492	483
	Hold	0.66	1.65	17.4	249	113	192	9.83	34.6	66.9	852	500	502
	H-S	0.62	1.17	19.9	199	110	194	9.93	34.9	66.5	836	480	482

TABLE 10.—CHANGES IN FAT AND TOTAL SOLIDS OF CHEESE DURING SIX MONTHS RIPENING AT 40° F.

Lot No.	Fat				Total solids		
	Age in months	½	3	6	½	3	6
	Treatment	%	%	%	%	%	%
P_1	Raw	37.5	37.9	39.0	68.7	68.7	70.8
	Hold	37.1	37.1	38.9	68.3	67.7	70.4
	H-S	37.5	38.0	38.0	68.4	68.4	69.4
P_2	Raw	33.4	35.6	33.9	66.4	67.2	68.7
	Hold	32.9	33.2	33.7	65.9	66.8	68.4
	H-S	33.2	33.4	34.0	65.6	66.4	67.6
P_3	Raw	36.4	36.4	38.5	67.5	68.3	71.6
	Hold	36.0	36.7	38.5	67.1	68.6	72.2
	H-S	36.4	36.8	38.6	67.5	68.5	72.0
P_4	Raw	35.6	36.1	36.2	67.3	69.1	69.0
	Hold	35.6	36.0	35.6	67.4	68.5	68.1
	H-S	35.8	36.3	36.2	67.4	68.8	68.4
P_5	Raw	35.6	36.2	35.9	68.3	68.8	68.8
	Hold	34.6	34.6	34.8	68.0	68.7	68.2
	H-S	35.8	35.7	35.8	68.5	68.3	68.7
P_6	Raw	35.4	35.3	35.9	67.7	67.3	68.0
	Hold	35.2	35.0	35.2	67.1	67.1	67.0
	H-S	35.6	35.3	35.7	67.7	67.3	67.0

TABLE 11.—STABILITY OF RIBOFLAVIN DURING RIPENING AT TWO TEMPERATURES
(Values in μg./100 g.)

Lot	Treatment	Time and temperature of storage						
		1 day	14 days		3 months		6 months	
			40° F.	58° F.	40° F.	58° F.	40° F.	58° F.
P_1	Raw	415	392	379	438	427	475	460
	Hold	376	276	288	378	348	454	459
	H-S	433	270	280	354	346	463	448
P_2	Raw	464	394	386	495	492	469	461
	Hold	404	402	388	471	443	486	464
	H-S	404	393	380	445	428	481	479
P_3	Raw	473	473	454	460	453	478	477
	Hold	450	451	436	493	486	490	486
	H-S	473	414	429	459	452	478	477
P_4	Raw	471	421	431	475	470	481	481
	Hold	477	419	423	486	469	492	490
	H-S	475	422	415	445	444	484	487
P_5	Raw	706*	465	459	417	402	442	450
	Hold	484	463	465	—	446	456	452
	H-S	478	478	477	451	446	467	461
P_6	Raw	483	472	475	454	456	464	468
	Hold	502	476	477	468	467	477	470
	H-S	482	490	478	458	455	467	472
Means—								
	Raw	462	439	431	455	450	468	466
	Hold	449	415	413	459	443	476	470
	H-S	458	411	410	435	429	473	471

*Not included in mean.

THE RETENTION OF NUTRIENTS IN CHEESE MAKING

III. THE CALCIUM, PHOSPHORUS AND RIBOFLAVIN CONTENTS OF CREAM, COTTAGE, BRICK AND BLUE CHEESE

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One factor which tends to restrict interest in cheese as a component of Canadian diets is the relatively limited number of varieties of cheese offered to the consuming public. It is generally agreed that an increase in the numbers of types of cheese would facilitate the promotion of cheese sales and result in a more nutritious, and probably cheaper, source of food for large sections of the population. This has been the experience in the United States where the sale of several foreign types of cheese brought about a noticeable increase in the per capita cheese consumption during the decade prior to the war.

Most varieties of cheese are known to be excellent sources of protein and the majority are also good sources of vitamin A activity. Wide variations in the methods of manufacture, however, cause differences in composition. This is particularly true of the mineral content. In addition, comparatively little is known regarding the water-soluble vitamins present in these varieties. It was for these reasons that a project was planned to study the calcium, phosphorus and riboflavin present in some special varieties of cheese made under controlled conditions. The varieties studied consisted of cream, cottage, brick and blue. The effect of an appropriate storage or ripening period upon riboflavin stability was also included in the study.

HISTORICAL

The methods employed in the manufacture of almost any variety of soft or fancy cheese are much more varied than those for cheddar. Differences in manufacturing methods which involve variations in acidities are now known to affect greatly the retention of minerals in the cheese. Wode (16) pointed out this relationship and his findings have been confirmed by others (8, 9, 10).

McCammon, Caulfield and Kramer (8) have reported the mean calcium and phosphorus contents of cream cheese made in their laboratory as 0.075 and 0.091%, respectively. These appear to be the only values in the literature. For cottage cheese these authors report values ranging from 0.09 to 0.128% calcium and 0.134 to 0.186% phosphorus. Garrett (2) found mean values of 0.08% calcium and 0.230% phosphorus on 102 samples of commercially made cottage cheese.

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[1] Joint contribution from the Departments of Dairying and Chemistry, O.A.C. and Department of Pediatrics Hospital for Sick Children, Toronto. Determinations for fat and total solids were made in the Dairy Chemistry Laboratory, O.A.C., while those for calcium, phosphorus and riboflavin were made at the Hospital for Sick Children.

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The literature appears to contain no riboflavin values for these two varieties of cheese. No recorded values for calcium, phosphorus or riboflavin were found for brick cheese although the riboflavin values reported by Burkholder, Collier and Moyer (1) for Limburger cheese might be expected to be similar.

Stilton cheese is somewhat analagous to blue cheese in that it is mould-ripened. Values for calcium, phosphorus and riboflavin are on record for this variety. Mattick (10) reports calcium values of from 0.207 to 0.258% and phosphorus values of 0.247 to 0.340% in commercially made samples of this variety. Houston and Kon (4) reports riboflavin values of 2.30 to 3.50 μg per g. of Stilton cheese.

Certain types of fancy cheese which develop a surface slime during the ripening process were found by Burkholder, Collier and Moyer (1) to show marked increases in their content of B-complex vitamins. This increase was attributed to the biochemical changes brought about by the micro-organisms in the slime of the cheese.

EXPERIMENTAL

In this study four lots of each variety were manufactured. The 16 lots were all made during the period of May-July, 1943, the dairy herd of the Ontario Agricultural College serving as the source of the milk. Of these varieties, brick and blue are subject to ripening processes and sampling of these types was therefore done at intervals during these periods. Cottage and cream cheese are highly perishable and were therefore stored for only 7 and 14 days, respectively. In view of the fact that there might be changes in riboflavin content during this period, assays for this vitamin were repeated at the end of these times. Table 1 has been prepared to outline more clearly the plan of the study.

Table 1.—Outline of studies on special varieties of cheese

Variety and Lot	Date	Schedule of analyses	
		Fat, T.S., NaCl, Ca, P, Ribo.	
Cream 1	4/6	Fresh cheese	(Ribo. again at 14 days)
Cream 2	10/6	Fresh cheese	
Cream 3	7/7	Fresh cheese	
Cream 4	8/7	Fresh cheese	
Cottage 1	1/6	Fresh cheese	(Ribo. again at 7 days)
Cottage 2	2/6	Fresh cheese	
Cottage 3	1/7	Fresh cheese	
Cottage 4	7/7	Fresh cheese	
		Fat, T.S., Ca, P., Ribo.	Fat, T.S., NaCl, Ribo.
Brick 1	8/6	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Brick 2	9/6	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Brick 3	14/7	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Brick 4	15/7	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Blue 1	12/5	Milk, whey	*Cheese at 1, 14 da., 3 and 6 mo.
Blue 2	13/5	Milk, whey	*Cheese at 1, 14 da., 3 and 6 mo.
Blue 3	29/6	Milk, whey	*Cheese at 1, 14 da., 3 and 6 mo.
Blue 4	30/7	Milk, whey	*Cheese at 1, 14 da., 3 and 6 mo.

* Analysis for Ca. and P. was carried out on 1-day-old cheese.

The method used in manufacturing the cream cheese was similar to that described by Roundy and Price (12), the cheese being made from 16% cream pasteurized at 143° F. for 30 minutes and homogenized at 1500 lb. pressure. Starter was used at the rate of 5% and rennet at the rate of 3 ml. per 1000 lb. During the 14 days storage period at 40° F. the cheese was held in 4 oz. glass jars.

In manufacturing the cottage cheese curd, the method outlined by Mull, Reid and Arbuckle (11) was followed. In each lot, skimmilk pasteurized at 143-145° F. for 30 min. was used; starter and rennet were added at the rate of 10% and 1.25 ml. per 1000 lb., respectively; and the curd was creamed on the morning following manufacture by stirring in enough 20% cream to give the cheese a fat content of about 4%. Salt was added at the rate of 1%. Samples were held in 12 oz. paraffined paper tubs during the 7-day storage period at 40° F.

The methods described by Wilson and Price (14) were largely followed for the brick cheese. Raw, warm, morning's milk was used exclusively. Lactic starter was added at the rate of 0.1% and rennet at the rate of 4 oz. per 1000 lb. Salt was added to these cheese by the dry method, rubbing it on all surfaces of the loaves on the first and second day following manufacture. One of the four lots could hardly be considered as being of even fair quality but this did not appear to affect the results of the trial. In this case the starter was inactive and the cheese developed a very gassy flavour and texture.

In the case of the blue cheese the first and third lots were made from raw milk according to the methods of Goss, Nielson and Mortensen (3) and Irvine (5) while raw, homogenized milk was used in the remaining two experiments. In the latter cases the method of Lane and Hammer (7) was employed. The mould powder used was purchased from the Department of Dairy Industry of the Iowa State College.

The brick cheese were ripened for the first two months at 58° F., being paraffined after the first two weeks. Storage for the remainder of the ripening period was at 40° F. The blue cheese was held at 50° F. for the first three months under conditions of high relative humidity. During this period they were scraped three times to remove excessive slime growth after which the cheese were tightly wrapped in tin foil and transferred to the 40° F. storage.

The problem of securing a representative sample of a substance like cream or cottage cheese is a difficult one. In the case of the cream cheese the curd was allowed to continue draining overnight at 40° F. The salt was then added and thoroughly worked in, after which three sub-samples were taken and thoroughly mixed together. A similar plan was followed in the case of the cottage cheese. For brick cheese, a quarter of a loaf was removed and split lengthwise in the manner in which a print of butter is sampled. In sampling the blue cheese a 45-degree wedge was removed from a cheese for analysing. This was subdivided into four pieces, two of which were wrapped in moisture-proof "Cellophane" and dispatched to each laboratory.

The methods of analysis for fat, total solids, calcium, phosphorus and riboflavin were those cited in a previous paper (6). Sodium chloride was determined according to the method described by Wilster *et al.* (15).

RESULTS

Cream Cheese

Table 2 indicates the results secured on this type of cheese.

TABLE 2.—CA, P, AND RIBOFLAVIN PRESENT IN CREAM CHEESE

Lot	Fat	T.S.	NaCl	Ca	P	Riboflavin	
						1 da.	14 da.
	%	%	%	mg. %	mg. %	μg/100 g.	μg/100 g.
1	41.99	52.00	—	82.4	86	265	320
2	39.19	49.24	—	86.4	86	323	325
3	32.30	42.04	1.53	—	—	273	251
4	42.91	52.53	1.13	—	—	260	267
Mean	39.07	49.70	—	—	—	280	291

It will be noted that lot No. 3 is above the legal limit for moisture content according to the Dairy Industry Act. Aside from this these lots of cheese were all quite typical of the product usually offered for sale. The high moisture content is one factor which contributes to the relatively low values for calcium and phosphorus but it is obvious that this variety is not equal to cheddar cheese as a source of these minerals. The results for riboflavin suggest that this vitamin suffers no destruction during a holding period of up to 14 days.

Cottage Cheese

Since a comparatively high acidity is developed in this process and since also the curd is usually subject to two or more washings, the values for nutrients are likely to bear little relationship to the nutrients originally present in the milk. For these reasons the values on the finished cheese only were determined. These are presented in Table 3.

TABLE 3.—CA, P, AND RIBOFLAVIN PRESENT IN COTTAGE CHEESE

Lot	Fat	T.S.	NaCl	Ca	P	Riboflavin	
						1 da.	7 da.
	%	%	%	mg./100 g.	mg./100 g.	μg/100 g.	μg/100 g.
1	3.18	20.31	0.75	87	137.6	293	260
2	3.09	20.63	0.95	89	140.0	—	288
3	1.71	21.15	1.05	79.2	161.6	317	276
4	2.58	19.97	1.02	—	—	251	308
Means	2.64	20.51	0.94	85	146	288	283

The relatively high moisture content of cottage cheese results in its lower nutritive value. On the basis of the mean values, riboflavin appears to be stable during this seven-day period.

Brick Cheese

As this variety was made from whole milk and the curd was not washed, it was possible to determine the values for nutrients in the milk,

whey and cheese and to assess the efficiency of the cheesemaking process with respect to retention of these factors. The results from the four vats have been averaged and are presented in Table 4. Table 8 in the Appendix gives the actual values for these nutrients and details of composition, etc.

TABLE 4.—LOSS IN WHEY AND RETENTION IN BRICK CHEESE OF CA, P, AND RIBOFLAVIN SHOWN AS PERCENTAGES OF THE AMOUNT ORIGINALLY PRESENT IN THE MILK

Means of four lots

—	Ca	P	Riboflavin
	%	%	%
Whey	26.7	37.7	56.9
Cheese (1 da.)	57.7	58.7	27.4
Total	84.4	96.4	84.3

These results indicate that mineral retention in brick cheese is of the same order as in raw-milk cheddar cheese. In view of the fact that there is no development of acidity in this process even up until the time curds are placed in the forms, one would anticipate a slightly higher retention of calcium in the cheese. The retention of riboflavin in the one-day-old cheese is significantly higher than in cheddar cheese, however, due no doubt to the fact that the moisture content and yield of cheese is higher than cheddar.

The development of a surface slime on these cheese during early ripening is a factor which might alter the riboflavin content during this interval. Largely for this reason a study was made of riboflavin stability during the ripening period. Results (Table 5) have been recalculated to a 35% moisture basis in order to obviate the error caused by shrinkage.

TABLE 5.—STABILITY OF RIBOFLAVIN DURING THE RIPENING OF BRICK CHEESE. RESULTS CALCULATED ON A 35% MOISTURE BASIS

Lot	Riboflavin (μg/100 g. 35% moisture cheese)			
	Age—1 da.	14 da.	1 mo.	3 mo.
1	598	550	473	485
2	632	600	504	474
3	682	520	507	508
4	624	550	546	564
Mean	634	555	508	508

These results indicate that after the first two or three weeks of ripening, riboflavin values are stable. During the period of slime formation and washing, however, there appears to be a significant loss of this factor.

Blue Cheese

In these experiments it was also possible to determine the percentages of nutrients lost and retained. The results are presented in Table 6 and in Table 9 in the Appendix.

TABLE 6.—LOSS IN WHEY AND RETENTION IN BLUE CHEESE OF CA., P., AND RIBOFLAVIN SHOWN AS PERCENTAGES OF THE AMOUNT ORIGINALLY PRESENT IN THE MILK

Means of four lots

——	Ca	P	Riboflavin
	%	%	%
Whey	46.1	48.1	58.5
Cheese (1 da.)	46.2	43.3	30.1
Total	92.2	91.4	88.6

High acidities are employed in blue cheese manufacture and these may account for the relatively poor retention of minerals in these trials. The values for calcium and phosphorus present in the cheese are much greater than those found in English Stilton by Mattick (10), however.

Values showing changes in riboflavin content during ripening have been calculated in the same manner as for brick cheese and are presented in Table 7.

TABLE 7.—STABILITY OF RIBOFLAVIN DURING THE RIPENING OF BLUE CHEESE. RESULTS CALCULATED ON A 35% MOISTURE BASIS

Lot	Age	Riboflavin (μg/100 g. 35% moisture cheese)			
		1 da.	14 da.	3 mo.	6 mo.
1		614	615	560	630
2	(Homo.)	590	620	571	654
3		670	620	560	608
4	(Homo.)	720	610	574	599
Mean		649	616	566	622

The above values are the highest so far encountered for riboflavin in any cheese studied in this project. They also indicate that here again riboflavin is not adversely affected by any of the chemical changes which occur during cheese ripening. The practice of homogenizing the milk which was followed in the case of lots 2 and 4 appears to have had no adverse effect upon the riboflavin content of the cheese.

DISCUSSION

In so far as mineral values are concerned, these results confirm the findings of McCammon, Caulfield and Kramer (8) to the effect that cheese of different varieties vary widely in mineral content. In the manufacture of those varieties in which high acidities are developed or in which the curds are washed with water, a marked reduction in calcium content particularly, is to be expected. Where these practices can be avoided or limited, the nutritive qualities of the cheese are benefited. Where cheese-making methods (e.g. cottage cheese) can be varied without affecting the

flavour and texture qualities of the product, the retention of additional nutrients should be a factor in determining what manufacturing procedure will be followed.

The mineral values on cream and cottage cheese, while indicating that these varieties are much poorer than the cheddar, brick and blue varieties, are still such that they rank very high in any list of calcium and phosphorus containing foods. The large proportion of these minerals retained by brick and blue cheese is a point which should highly recommend these varieties to dietitians.

These varieties all appear to be good sources of riboflavin, particularly brick and blue cheese. On the basis of their solids-not-fat content, cream and cottage cheese rate very well.

The results obtained in this study are not in accord with the findings of Burkholder, Collier and Moyer (1) in regard to increases occurring during the ripening periods of some semi-hard cheeses. On the other hand they agree with Sullivan, Bloom and Jarmol (13) who found riboflavin to be quite stable during ripening.

SUMMARY

A study has been made of the calcium, phosphorus and riboflavin contents of cream, cottage, brick and blue cheese. In the case of the latter two varieties, the proportions of these nutrients originally present in the milk which were retained in the cheese, were determined. In addition the stability of riboflavin during the ripening periods of brick and blue cheese was also studied. The average results on a limited number of batches were as follows:

Cream cheese contained 84.4 mg. % calcium, 86 mg. % phosphorus, and 280 μg. per 100 g. of riboflavin:

Cottage cheese contained 85 mg. % calcium, 146 mg. % phosphorus and 288 μg. per 100 g. of riboflavin:

In brick cheese, of the original nutrients present in the milk, 57.7% of the calcium, 58.7% of the phosphorus and 27.4% of the riboflavin were retained in the cheese.

In blue cheese the corresponding values for retention were: calcium, 46.2%; phosphorus, 43.3%; and riboflavin, 30.1%.

The riboflavin content of the cream and cottage cheese did not change when these varieties were stored for short periods. It also appeared to be quite stable in the ripening processes of brick and blue cheese.

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APPENDIX

Table 8.—Detailed results* on brick cheese

Lot No.	Milk					Whey				
	Fat	T.S.	Ca	P	Ribo.	Fat	T.S.	Ca	P	Ribo.
1	1.23	11.90	130.5	75	227	0.25	6.75	43.3	33.5	157
2	3.69	12.49	134.5	76	257	0.30	6.94	40.0	33	164
3	3.89	11.89	—	—	220	0.31	6.96	—	—	206
4	4.19	12.78	—	—	255	0.33	6.96	—	—	186

Cheese (one-day-old)

Lot	Yield	Fat	T.S.	Ca	P	Ribo.
1	11.21	27.6	55.2	728	432	508
2	12.14	28.9	55.3	640	420	538
3	12.19	30.1	55.8	—	—	585
4	13.07	31.4	55.3	—	—	530

Cheese

Lot	Age—14 da.				1 mo.				3 mo.			
	Fat	T.S.	NaCl.	Ribo.	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.
1	29.5	60.1	1.57	508	30.5	62.3	1.72	453	31.8	63.4	1.77	473
2	30.4	58.8	1.87	544	31.3	61.6	2.16	478	33.2	64.7	2.11	471
3	34.6	65.1	1.98	522	34.7	65.6	2.20	512	38.6	71.6	3.25	559
4	34.0	60.8	1.86	515	35.7	63.2	2.09	531	37.3	65.0	1.93	564

*Fat, T.S., NaCl. in percent.
Ca., P. in mg./100 g.
Riboflavin in μg/100 g.

TABLE 9.—DETAILED RESULTS* ON BLUE CHEESE

Lot No.	Milk					Whey				
	Fat	T.S.	Ca	P	Ribo.	Fat	T.S.	Ca	P	Ribo.
1	4.42	13.24	128.5	86	208	0.37	7.00	70.3	49	154
2	4.08	12.53	128.5	86	332	0.32	6.84	64.8	47.5	165
3	4.13	12.84	129.5	82	256	0.32	6.79	37.8	47.5	170
4	3.86	12.46	118.5	82	280	0.30	6.87	—	—	192

Cheese (one-day-old)

Lot	Yield	Fat	T.S.	Ca	P	Ribo.
1	13.46	30.5	53.6	388	252	506
2	14.32	26.8	48.7	468	292	441
3	13.83	29.3	53.0	312	252	546
4	13.59	28.7	52.1	—	—	579

Cheese

Lot	Age—14 da.				3 mo.				6 mo.			
	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.
1	31.4	57.1	2.81	541	39.1	67.4	4.31	577	39.2	68.3	4.08	663
2	27.9	53.8	4.33	513	35.2	64.0	4.81	564	33.8	66.4	6.05	668
3	30.4	55.7	2.79	530	42.4	73.1	4.05	646	40.8	73.0	4.35	683
4	29.9	56.8	3.20	532	39.6	72.5	4.59	640	40.3	75.1	4.28	693

* Fat, T.S., NaCl. in percent.
Ca., P. in mg./100 g.
Riboflavin in μg/100 g.

GROWTH OF BACON TYPE HOGS[1]

RATES OF GAIN AT SPECIFIC LIVE WEIGHTS

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Published data giving average growth rates of Canadian bacon type hogs are scant. Crampton (2) and, Ashton and Crampton (1) have published growth curves for bacon type hogs fed at Macdonald College, but these values may or may not represent pigs fed at other Canadian centres. To secure suitable data for such curves, management practices must provide live weight records of pigs at short intervals, and preferably not exceeding 14 days. While all Canadian stations do not record weights at such short intervals, a number of them do weigh their test pigs biweekly.

SOURCE AND NATURE OF THE DATA

The Dominion Experimental Farm at Nappan, N.S. follows the above mentioned procedure, with the result that in January, 1945, there were available at this Station biweekly live weight records for 183 group-fed hogs. In such data was material for the construction of a swine growth curve, about which individual variation could be indicated. Group treatment, however, prevents the collection of individual feed consumption data as well as a measure of the individual variation, so feed intake has not been considered in this study.

The hogs used in this study were of Yorkshire breeding. Their dams were bred at the Nappan Experimental Farm and were almost all daughters, grand-daughters, or great-grand-daughters of the Swedish-bred sire Valter of Svalof-179616-. Litters were farrowed in both early spring and fall, and creep-fed from 2 weeks of age. The males were castrated when one month old and all pigs were weaned at approximately 8 weeks.

The hogs were allotted to experimental feeding pens of 4 or 5 hogs each at 65-75 days of age. All groups were full hand fed the meal allowance, with water, thrice daily from weaning to an average weight of 100-125 pounds and thereafter twice daily.

The basal fraction of the rations for most of the pigs consisted of feed barley, oats and wheat or shorts. Barley generally constituted about 50% of the rations except for 25 hogs which received barley only as the basal feed.

White-fish meal constituted the entire protein supplement for the greater number of the hogs. In two tests involving 72 pigs, the protein-

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mineral supplement was made up as follows: Tankage 50%; white-fish meal 15%; linseed oilmeal 20%; bone meal 5%; ground limestone 5%; and salt 5%. A few hogs in one test were fed oily-fish meal, or tankage, as the protein supplement. A mineral mixture, made up of one meal 40%, ground limestone 40%, and salt 20%, was fed at 1-2% of the basal feed allowance to all hogs fed a single high protein feed.

The rations during the first period for all groups fed the mixed protein-mineral supplement consisted of 85 parts basal feeds and 15 parts supplement, while the proportion of supplement was reduced to about 10% in the last period. The various protein supplements used have not resulted in any appreciable difference in the estimated digestible protein content of the rations fed. The final feed mixtures were supplemented with one teaspoonful of cod liver oil daily for each animal in all groups under 100 pounds average weight.

TREATMENT OF DATA

The relating of daily gains of pigs to specific body weights requires data on live weights and interval live weight increases. The experimental method followed at Nappan of arranging many of the test pigs into groups of 5 precluded equal representation of the sexes on any one ration so no attempt was made here to determine these differences. The combining of the data from the two sexes is further warranted by the study of Ashton and Crampton (1) which showed the rate of gain to be statistically the same for male and female pigs of identical live weights.

The system of biweekly weighing practised at this Station provided, for each pig on test, several live weight records and consequently a number of 14-day and/or weight interval gains. Live weight values to correspond to average daily gain values over the time and/or weight intervals were taken as the midpoints between the two appropriate weighings. Thus for example the values for a pig whose live weights at successive periods were 151 pounds and 169 pounds are: average daily gain 1.3 pounds, and the midpoint or weight to which this gain value is applied is 160 pounds.

Following the determination of these midpoints and their respective daily gains, the latter were brought together at live weight intervals of 10 pounds. For example, all gains made at mid-weights from 155 to 164 pounds inclusive were put into the 160-pound group. The mean gain and the standard deviation were calculated for each live weight group. These values were then plotted against live weight and the resulting curves smoothed by Fisher's Summation Method of Fitting Polynomials (3).

RESULTS AND DISCUSSION

The tabulated values for the hogs in this study appear in Table 1 and their trend is graphically depicted in Figure 1 by a third degree polynomial.

TABLE 1.—AVERAGE DAILY GAINS AND THE STANDARD DEVIATIONS FOR YORKSHIRE PIGS FROM 30 TO 200 POUNDS LIVE WEIGHT

Weight classes	Average daily gain	
	Observed values	Third degree polynomial
lbs.	lbs.	lbs.
30	0.73 ± 0.15	0.72 ± 0.19
40	0.84 ± 0.21	0.88 ± 0.20
50	1.00 ± 0.28	1.02 ± 0.22
60	1.19 ± 0.27	1.14 ± 0.24
70	1.31 ± 0.28	1.24 ± 0.25
80	1.33 ± 0.32	1.33 ± 0.27
90	1.41 ± 0.26	1.40 ± 0.28
100	1.40 ± 0.35	1.45 ± 0.30
110	1.40 ± 0.24	1.50 ± 0.31
120	1.50 ± 0.25	1.54 ± 0.33
130	1.61 ± 0.29	1.58 ± 0.35
140	1.70 ± 0.31	1.61 ± 0.36
150	1.64 ± 0.37	1.64 ± 0.38
160	1.73 ± 0.42	1.68 ± 0.39
170	1.76 ± 0.36	1.72 ± 0.41
180	1.64 ± 0.37	1.77 ± 0.42
190	1.79 ± 0.50	1.82 ± 0.44
200	1.95 ± 0.56	1.90 ± 0.45

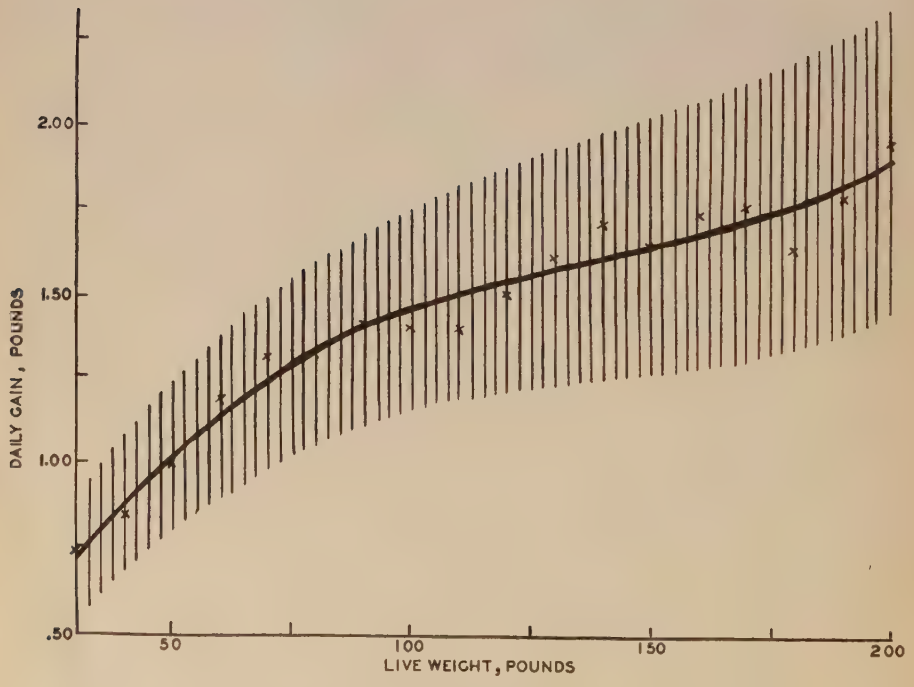

FIGURE 1. Average daily gain of Yorkshire pigs from 30 to 200 pounds live weight. Shaded area marks limits of ± one standard deviation.

A comparison of this curve with the one by Ashton and Crampton (1) appears in Figure 2. The curve in this study shows considerably less change in slope, and slower gains over the greater part of its length, than that from Macdonald. All of the mean gains but one (at 50 pounds) below 160 pounds are significantly different at odds of 19 : 1.

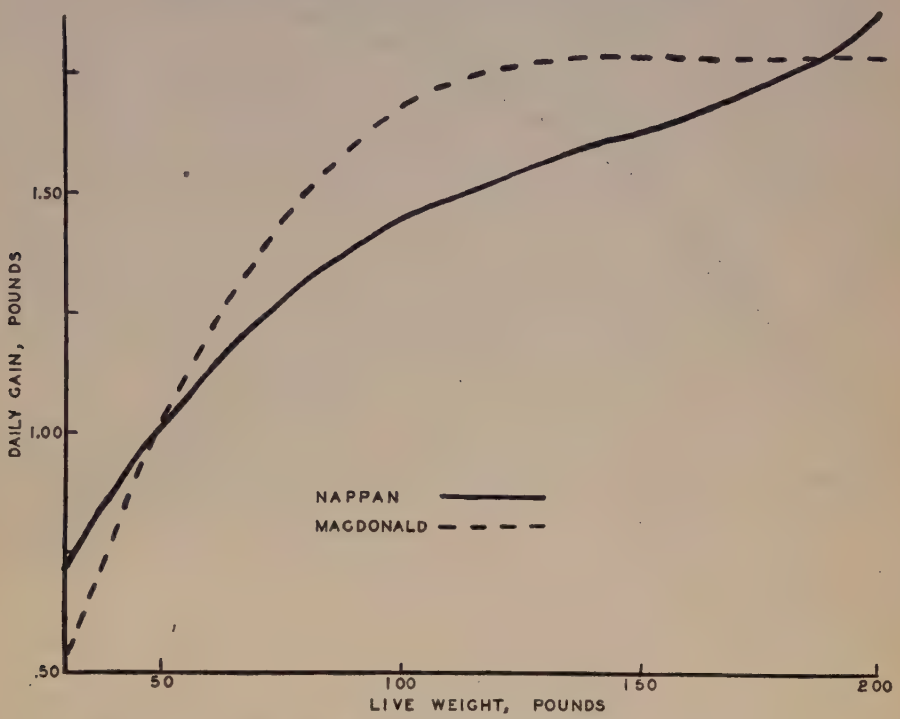

FIGURE 2. Average daily gain of pigs fed at Nappan and Macdonald.

It will be noted that the two curves cross one another at the 50-pound point and again at 185 pounds. The higher rate of gain for the small pigs at Nappan would appear to be the result of creep-feeding during the nursing period and probably to a lesser extent to the gradual change from stock to test rations.

Pigs reared at Macdonald College are not provided with creep feed but are encouraged to steal from the sow's trough. The sows receive a starter-grower mixture throughout their gestation and lactation period. Following weaning the young pigs continue to receive the same ration until they are placed on trial when they are immediately given their respective test rations in individual pens.

The accelerated rate of gain of the Nappan pigs over 185 pounds in weight does not appear to be the result of ration differences, since smoothed curves in Figure 3 based on other groups of hogs from these stations, whose treatment has been similar, show the same differences in trend as observed in Figure 2. The animals represented in Figure 3 were part of a co-operative feeding trial in which special efforts were made to standardize test

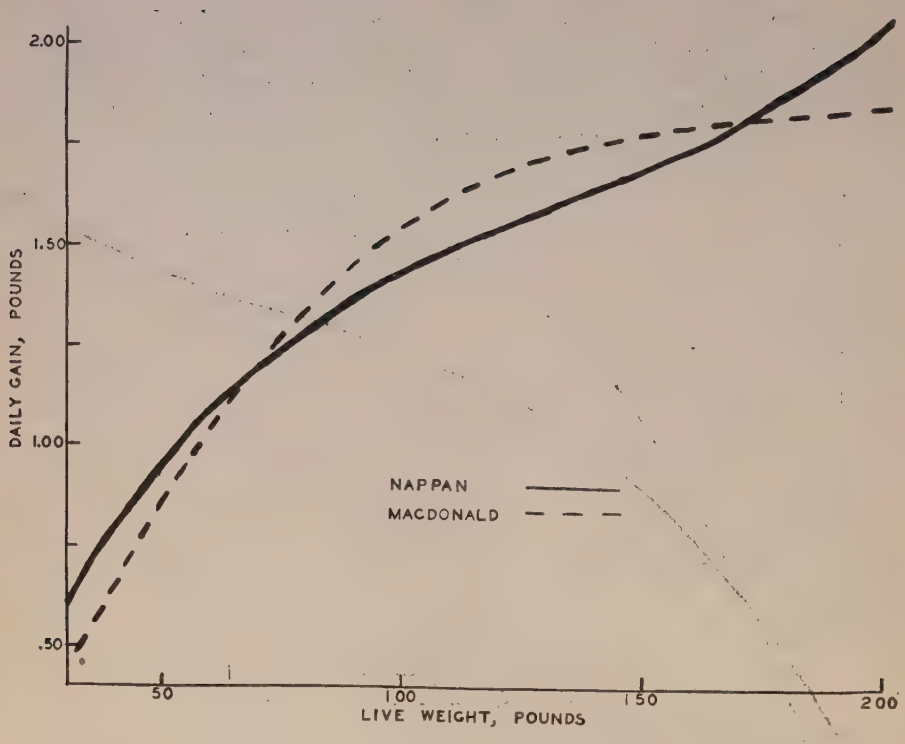

FIGURE 3. Average daily gain of Nappan and Macdonald fed pigs, receiving the same rations.

conditions at several feeding stations. The feed was prepared by a single commercial feed firm and distributed by it to all the stations at the same time. There is some Nappan blood in the Macdonald herd so the breeding is not greatly different. It would appear, therefore, that feeding management has been the cause of the difference in the shape of the curves.

A study of the live weights of all the animals in each group of the Nappan pigs disclosed a wide range in their weights at any particular time. In many instances when the average weight of the group was 100 pounds the lighter ones were only 80 pounds while the heavier ones were 120 pounds. Since this was the weight at which the protein in the feed was reduced, the change occurred late for the large pigs and early for the small ones. This gave a low protein intake for the small pigs in each group because of: (1) premature reduction of protein in the ration, and (2) low feed intake because of competition at the feed trough. Thus it seems logical to expect lower than average gains on these pigs following their attaining a weight of 70 pounds. Figure 4 would seem to bear out this hypothesis.

The greater slope of the curve as it approaches the 200-pound weight is apparently due to the faster growing pigs rather than the slower ones. Comparison of the curves for pigs requiring 14 and 18 weeks, respectively, of feeding to reach market weight show the rate of gain for the latter group to be practically constant after the pigs reach 100 pounds in weight, while the rate for the former group continues to increase (Figure 4). This must

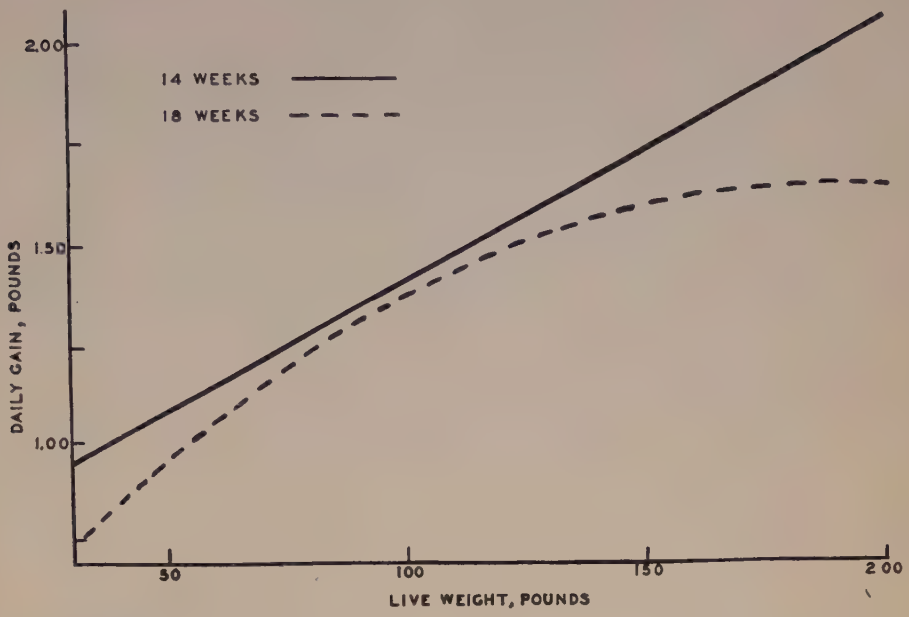

FIGURE 4. Average daily gain of pigs requiring 14 and 18 weeks of test feeding to reach 200 lbs. live weight.

surely mean the 18-week group could have consumed more feed if they had had access to it. Since the 14-week pigs were out of the picture, at this time, the feed allowance must be the limiting factor in feed consumption.

SUMMARY

Data are presented indicating average daily live weight increases of group-fed Yorkshire pigs at various live weights from 30 to 200 pounds.

This study indicates that the rates of live weight increase for bacon type pigs are influenced by feeding practice.

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1. ASHTON, G. C., and E. W. CRAMPTON. Growth and feed consumption of bacon hogs. II. Rates of gain and feed consumption according to weight of pig. Sci. Agri. 23 : 11. 1943.

2. CRAMPTON, E. W. Growth and feed consumption of bacon hogs. Sci. Agri. 19 : 12. 1939.

3. FISHER, R. A. Statistical methods for research workers. Oliver and Boyd. London. 7th Edition, p. 142. 1938.

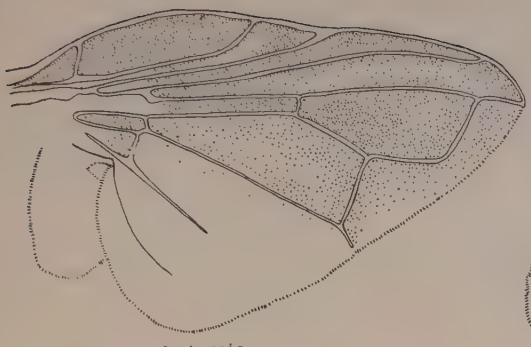
ERRATUM

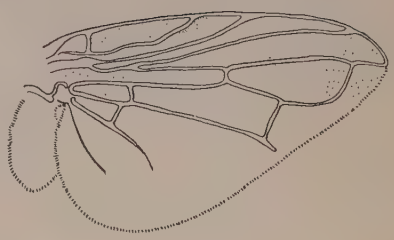
In the article entitled, "A revision of the North American species of the *Phasia* complex (Diptera, Tachinidae)", by A. R. Brooks in the July, 1945, issue of *Scientific Agriculture* (Vol. 25, No. 11, pp. 647-679), two plates were omitted and the legend for Plate II (page 651) is incorrect. The legend for Plate II is as follows:

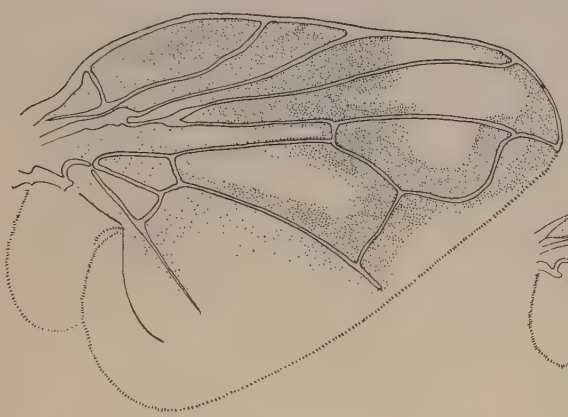
"Figures 8-13. Male wings. Drawn to same scale."

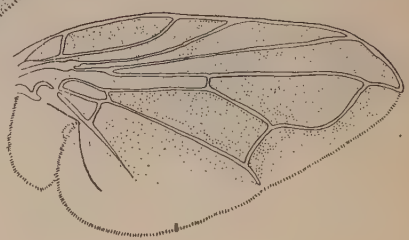
Plates III and IV appear on succeeding pages of the current (August, 1945, Vol. 25, No. 12) issue, and should be cut out and inserted in their proper place in the July issue.

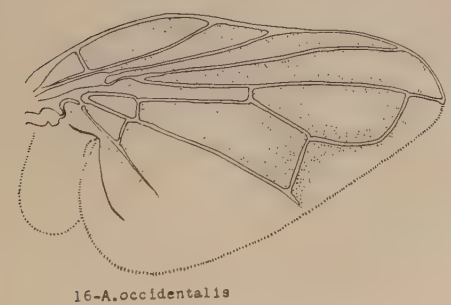
PLATE III

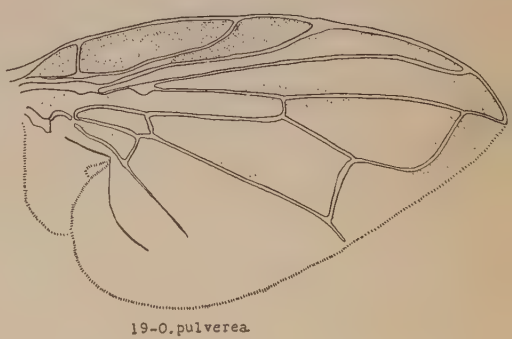






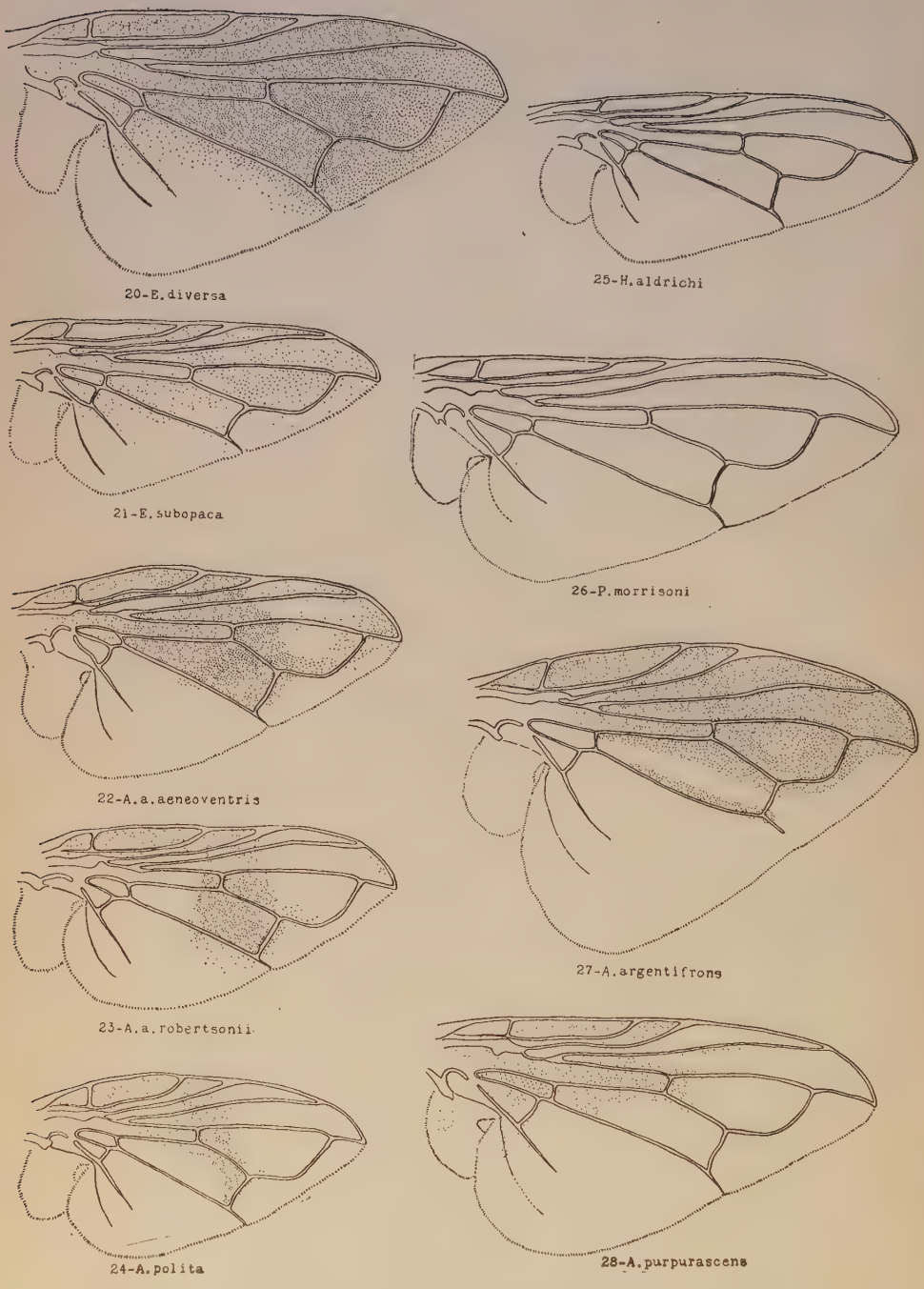






FIGURES 14-19. Male wings. Drawn to same scale.

PLATE IV



FIGURES 20-28. Male wings. FIGURES 20-24 drawn to same scale as FIGURES 7-19; FIGURES 25-28 somewhat enlarged.

SUBJECT INDEX TO VOLUME 25

AUTHOR INDEX